SOUNDSCAPE DESIGN OF WATER FEATURES USED IN OUTDOOR SPACES WHERE ROAD TRAFFIC NOISE IS AUDIBLE

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ABSTRACT

This research focused on the soundscape design of a wide range of small to medium sized water features (waterfalls, fountains with upward jet(s), and streams) which can be used in gardens or parks for promoting peacefulness and relaxation in the presence of road traffic noise. Firstly, the thesis examined the audio-visual interaction and perceptual assessment of water features, including the semantic components and the qualitative categorisation and evocation of water sounds; and secondly, the thesis investigated the effectiveness of the water features tested in promoting relaxation through sound mapping. Different laboratory tests were carried out, and these included paired comparison tests (audio-only, visual-only and audio-visual tests), semantic differential tests, as well as tests aimed at the qualitative categorisation and evocation of water features. Sound maps of the water generated sounds were developed through the use of propagation models based on either point or line sources. Three acoustic zones ('water sounds dominant zone', 'optimum zone' and 'RTN dominant zone' (RTN: road traffic noise)) were defined in the maps as the zones where relaxation/pleasantness can be promoted over a 20 m × 20 m area for different road traffic noise levels. Paired comparisons highlighted the inter-dependence between uni-modal (audio-only or visual-only) and bi-modal (audio-visual) perception, indicating that equal attention should be given to the design of both stimuli. In general, natural looking features tended to increase preference scores (compared to audio-only paired comparison scores), while manmade looking features decreased them. Semantic descriptors showed significant correlations with preferences and were found to be more reliable design criteria than physical parameters. A principal component analysis identified three components within the nine semantic attributes tested: "emotional assessment," "sound quality," and "envelopment and temporal variation." The first two showed significant correlations with audio-only preferences, "emotional assessment" being the most important predictor of preferences, and its attributes naturalness, relaxation, and freshness also being significantly correlated with preferences. Categorisation results indicated that natural stream sounds are easily identifiable (unlike waterfalls and fountains), while evocation results showed no unique relationship with preferences. The results of sound maps indicated that small to medium sized water features can be used mainly in environments where road traffic noise levels are equal or lower than 65 dBA.

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Galbrun, L., and Ali, T. T. (2013). *Acoustical and perceptual assessment of water sounds and their use over road traffic noise*. The Journal of the Acoustical Society of America, **133(1)**, 227–237, 2013.

Galbrun, L., and Ali, T. T. (2013). *Acoustical and perceptual assessment of water sounds and their use over road traffic noise*. The Journal of the Acoustical Society of America, **133(1)**, 227–237, 2013.

Ali, T.T. (2012). *Acoustical design of water features and their use for road traffic noise masking*. PhD Thesis, Heriot Watt University, October 2012, Edinburgh.

Ali, T.T. (2012). *Acoustical design of water features and their use for road traffic noise masking*. PhD Thesis, Heriot Watt University, October 2012, Edinburgh.

ISO 9613-2. (1996). *Acoustics-Attenuation of sound during propagation outdoors-Part2: General method of calculation*. International Organization for Standardization, Genève, Switzerland.

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GLOSSARY OF SYMBOLS

A	Absorption area (m^2)
	Total attenuation between source and receiver (dB)
A_{atm}	Attenuation due to atmospheric absorption (dB)
A_{bar}	Attenuation due to the presence of barriers (dB)
A_{div}	Attenuation due to geometrical divergence (dB)
A_{gr}	Attenuation due to the ground effect (dB)
A_{misc}	Attenuation due to other miscellaneous effects (dB)
D_c	Directivity correction (dB)
D_{Ω}	Additional term for directivity correction (dB)
E	Acoustic energy (N m/s)
$Exp(\beta)$	Odds- ratio in logit binary model
F	Fluctuation strength (vacil)
	F-ratio
G	Ground factor
H	Kruskal-Wallis statistic
I	Sound intensity (W/m^2)
	Maximum sound intensity (W/m^2)
I_{av}	Average intensity (W/m^2)
I_0	Reference intensity (10^{-12} W/m^2)
$I(\theta)$	Sound intensity passing through an area in the direction of its normal (W/m^2)
K_I	Penalty for impulses
K_R	Penalty for time of day
K_S	Penalty for certain sources and situations (seasonal correction and type of environment)
K_T	Penalty for tone and information content
L	Loudness level (phon)
	Length of the source (m)
ΔL	Loudness level difference (phon)
L_{Aeq}	A-weighted equivalent continuous noise level (dBA)
$L_{Aeq,24h}$	A-weighted equivalent continuous noise level over 24h (dBA)
$L_{Aeq,8h}$	A-weighted equivalent continuous noise level over 8h (dBA)
$L_{eq,T}$	Equivalent continuous noise level (dB)

$L_{AT}(DW)$	A-weighted sound pressure level in downwind conditions (dBA)
$L_{fT}(DW)$	Equivalent continuous downwind octave-band sound pressure level (dB)
L_{Amax}	A–weighted maximum sound pressure level (dB)
L_{A10}-L_{A90}	Temporal variation in level (dB)
L_{Ceq}-L_{Aeq}	Low frequency content (dB)
L_{Fmax}	Maximum sound level over a fast time constant (dB)
L_{Fmin}	Minimum sound level over a fast time constant (dB)
L_{Smax}	Maximum sound level over a slow time constant (dB)
L_{Smin}	Minimum sound level over a slow time constant (dB)
L_{day}	Day-noise level (7-19h) (dB)
L_{den}	Day−evening-night noise level (dB)
L_{dn}	Day-night equivalent noise level (dB)
$L_{evening}$	Evening–noise level (19-23h) (dB)
L_{mask}	Background noise level not requiring masking (dBA)
L_n	Noise level exceeded *n*% of the time (dB)
L_{night}	Night–noise level (23-7h) (dB)
L_r	Rating sound level (dB)
L_I	Sound intensity level (dB re 10^{-12} W/m^2)
L_p	Sound pressure level (dB 2 × 10^{-5} Pa)
L_w	Sound power level (dB re 10^{-12} Watts)
L_{10}	Noise level exceeded 10% of the time (dB)
L_{50}	Noise level exceeded 50% of the time (dB)
L_{90}	Noise level exceeded 90% of the time (dB)
N	Loudness (sone)
N'	Specific loudness (sone)
Q	Directivity
R	Roughness (asper)
R^2	R-squared for linear regression
Nagelkerke R^2	Nagelkerke R-squared for binary regression
S	Sharpness (acum)
	Surface area (m^2)
T	Averaging time period (s)
U	Mann-Whitney statistic
W	Sound power (Watts)
	Kendall's coefficient of concordance

	Wald statistic
W_0	Reference sound power (10^{-12} Watts)
-2LL	The likelihood ratio test
a	Height of a planar source (m)
b	Length of a planar source (m)
	Coefficient of independent variables in linear regression
d	Source-receiver distance (m)
d_0	Reference Source-receiver distance (m)
d_p	Source-to-receiver distance projected onto the ground plane (m)
d_1	Optimal distance from water features (m)
d_2	Optimal distance from water features (m)
f	Frequency (Hz)
	Resonant frequency of a bubble in an infinite volume of water (Hz)
f_{mod}	Modulation frequency (Hz)
h_m	Mean height of the propagation path above the ground (m)
h_s	Height of the source above the ground (m)
h_r	Height of the receiver above the ground (m)
p	Sound pressure (N/m^2, Pa)
	Root – mean – squared pressure (Pa)
	probability
p_0	Reference pressure (2×10^{-5} Pa)
r	Water bubbles' radius (m)
	Source-receiver distance (m)
t	Time (s)
	Period of wave (s)
	t-statistic
$\bar{\alpha}$	Average absorption coefficient
α_t	Attenuation coefficient for atmospheric absorption (dB/m)
β	Coefficient of independent variables in logit model
θ	Angle between the direction of propagation and the area normal (° degree)
ρ	Spearman's correlation

EM	Energetic masking
IM	Informational masking
KMO	Kaiser-Meyer-Olkin statistic

PCA	Principal Component Analysis
SD	Standard deviation
S/N	Signal-to-noise ratio (dB)
SPL	Sound pressure level (dB)
RTN	Road traffic noise (dB)

LIST OF CONFERENCES AND PUBLICATIONS

F.M.A. Calarco and L. Galbrun, Audio-visual interaction and perception of waterscapes used over road traffic noise, *Proceedings of InterNoise 2013*, paper no. 0831, Innsbruck, Austria, 15-18 September 2013.

F.M.A. Calarco and L. Galbrun, Semantic assessment of water features used over road traffic noise, *Proceedings of Forum Acusticum 2014*, paper no. R22_2, Krakow, Poland, 7-12 September 2014.

L. Galbrun and F.M.A. Calarco, Audio-visual interaction and perceptual assessment of water features used over road traffic noise, *J. Acoust. Soc. Am.*, **136(5)**, 2609-2620, 2014.

F.M.A. Calarco and L. Galbrun, Soundscape design and mapping of water features used over road traffic noise, *Proceedings of InterNoise 2015*, 9-12 August 2015, San Francisco, California, USA.

F.M.A. Calarco and L. Galbrun, Soundscape design and mapping of water features used over road traffic noise for promoting relaxation, to be submitted to the *Journal of Landscape and Urban Planning* in November 2015.

F.M.A. Calarco and L. Galbrun, A review of water features' design towards a soundscape approach, to be submitted to *Acta Acustica united with Acustica* in December 2015.

CHAPTER 1

Introduction

1.1 General introduction

This thesis examined the soundscape design of small to medium sized water features which can be installed in gardens or parks in view of promoting relaxation where road traffic noise (RTN) is audible. Although the analysis focused on road traffic noise and outdoor environments, it can be noted that the water sounds examined are representative of features that can be installed in both outdoor and indoor spaces such as hotel lobbies, offices, and restaurants.

The research presented concentrates on the design of water features through a soundscape approach. Soundscape was originally defined as “the study of the effects of the acoustic environment on the physical responses or behaviour of those living in it” (Schafer, 1994). This concept has been adopted in community noise control as a way to account for environmental noise in a positive way (Raimbault and Dubois, 2005), meaning that sound can be considered as a “resource” to be managed rather than a “waste” product (Brown and Muhar, 2004). According to this approach, introducing “wanted” sounds has been widely recognised as a mean to improve soundscape perception. In this context, water sounds have often been identified as the best sounds to use for enhancing the urban soundscape in view of reducing stress and improving quality of life (Kang, 2007) (Jeon *et al.*, 2010). However, the evaluation of soundscape quality is rather complicated due to its inherent connection with the subjective perception of individuals (Kang, 2007) (Brown *et al.*, 2011). For that reason, there is a need to further investigate perception of water sounds in view of improving soundscape quality while designing an acoustic environment.

1.2 Justification of the research

Noise pollution has long been recognised as affecting quality of life and well-being; and, over the past decades it has increasingly been identified as an important public health issue (European Environment Agency, 2014). In the European Union, road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels above the action levels (day−evening‑night level, L_{den} > 55 dBA) defined by the Environmental Noise Directive (END) (European Communities, 2002) (European Environment Agency, 2014). The END introduced a common approach intended "to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise" (European Communities, 2002). This refers not only to the quieting of already noisy areas, but also to the protection of quiet areas against increases of environmental noise. In this context, the acoustic use of water generated sounds has been widely recognised as a potential mean for masking annoying urban noise by taking advantage of their distracting effect as "wanted" sounds (Watts *et al.*, 2009), as well as improving soundscape perception due to their inherent positive qualities (Kang, 2007).

The soundscape approach (physical characteristics and mental perception of the aural environment (Schafer, 1994)) has provided an innovative and strategic method for designing water features from an acoustic point of view, by combining designable factors with objective acoustic measures and the subjective perception of the acoustic environment. Different designs can greatly affect the way in which water features are perceived both aurally and visually, but only a few recent studies have examined the physical and perceptual properties of water features in view of providing evidence-based design solutions (Watts *et al.*, 2009) (Jeon *et al.*, 2010) (Nilsson *et al.* 2010) (De Coensel *et al*., 2011) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013) (Rådsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013). Most of these studies concentrated on the use of water sounds over road traffic noise, and examined auditory preferences of water sounds in the context of tranquillity and relaxation, with limited consideration given to visual preferences (Watts *et al.*, 2009) *(Jeon et al.*, 2010) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013) (Hong and Jeon, 2013). As a consequence, the understanding of how to design water features from an audio-visual perspective is still limited.

Additionally, the principles and concepts applied to water features' design have typically focused so far on the central visual-aesthetic aspects of the water structures, the settings and available space, the type of installations and features components such as basin, pumps or the water system distribution by considering landscape/architectural or engineering approaches (Downing, 1977) (Booth, 1989) (Dreiseitl and Grau, 2005) (Zimmermann *et al.*, 2011) (CISBE, 2004). Therefore, little attention has often been paid to acoustic criteria at the very early stage of the design process, relegating the problem to acoustic post-design consulting (Fowler, 2013). Acoustic criteria did not always appear to have figured in water features' design and this failure can presumably be attributed to a lack of knowledge of how to predict and plan the effectiveness of acoustic masking in any particular setting (Brown and Rutherford, 1994). In this context, only few previous research have meticulously examined the masking properties of water sounds used over road traffic noise (Brown and Rutherford, 1994) (Boubezari and Coelho, 2004) (Nilsson *et al.*, 2010) (Axelsson *et al.*, 2014), but these were only limited to few types of large sized water features. Therefore, there is still a limited knowledge about what type of water feature is most effective for masking a specific level of road traffic noise under a specific context (e.g. relaxation/peacefulness /tranquillity or freshness/excitement/vibrancy), as the intended use of the surrounding space where the features might be installed is crucial for design.

In this context, the research presented here aims at filling these gaps by examining the soundscape design of water feature used over road traffic noise in view of promoting relaxation and peacefulness. In particular, this work focuses on investigating how the acoustical and visual design of water features can affect preferences and perception of the water sounds. Furthermore, the effects of subjective categorization and evocation properties of the water sounds on perception are also examined. Finally, the research focuses on sound mapping design by examining the effectiveness of the water structures tested when they are used over different ranges of road traffic noise levels.

1.3 Aims and objectives

The main aim of this thesis is to develop a better understanding and knowledge for the soundscape design of a large variety of small to medium sized water features which can be installed in gardens or parks where road traffic noise is audible, in view of promoting relaxation and peacefulness. More specifically, the work focuses on the perceptual assessment of water features used over road traffic noise by investigating their auditory and visual impact on perception. Additionally, the research examines the effect of the water displays rather than their background, and the qualitative characterisation of water sounds is also considered to gain a better understanding of the factors affecting water sounds' preferences. Furthermore, sound mapping design is considered to provide evidence-based design solutions which can be used when choosing and installing water features of small to medium sizes. All these aspects highlight the originality of this work. The objectives of the research are:

1. To identify the preferred water sounds and visual displays of small to medium sized water features (waterfalls, fountains and streams) for improving relaxation within

gardens and parks where road traffic noise is audible (Chapter 4).

2. To investigate the relationship between acoustic/psychoacoustic parameters and subjective perception of water sounds (Chapter 4).
3. To identify the principal semantic components affecting perception of water sounds (Chapter 5).
4. To investigate the relationship between semantic components and acoustic/ psychoacoustic parameters, as well as the preferences of water sounds (Chapter 5).
5. To examine how subjective categorization and evocation properties of the water sounds can affect aural perception (Chapter 6).
6. To examine the sound pressure level effectiveness of small to medium sized water features used over different ranges of road traffic noise levels, within the context of relaxation (Chapter 7).
7. To identify the optimal distances from the water features tested where relaxation can be promoted (Chapter 7).

The findings obtained will ultimately be useful in providing design guidelines of water features used for improving soundscape perception of outdoor environments.

1.4 Methodology

This works follows from previous research (Galbrun and Ali, 2013) which examined the acoustical and perceptual assessment of water sounds and their use over road traffic noise. Different water features were tested in the laboratory by Galbrun and Ali (2013) by varying different design parameters such as the waterfalls' width and edge, height of falling water, impact material and flow rate. From this pool of data, ten water features (waterfalls, fountains and streams) have been selected as being representative of a large variety of acoustical and visual conditions. Compared to the twelve features examined by Galbrun and Ali (2013), the selection excludes hard impact surfaces as these were poorly rated when compared with water as the impact material (Galbrun and Ali, 2013).

In order to achieve the main objectives of this research project, four different methodological approaches have been used:

1. Audio-visual tests in uni-modal (audio-only and visual-only) and bi-modal (audio-visual) sensorial conditions (to address objectives 1 and 2).
2. Semantic differential tests (to address objectives 3 and 4).
3. Categorisation and evocation tests (to address objective 5).

4. Development of sound maps (to address objectives 6 and 7).

1.4.1 Audio-visual tests

Three different tests were carried out using a paired comparison method: a listening test, a visual test and an audio-visual test. The aim was to identify the preferred water sounds, the visual impact of water features' displays, and the audio-visual interaction between preferences.

These tests were carried out in the anechoic chamber of the School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University. Subjects who reported normal hearing ability participated in all tests which were typically carried out over two sessions. During each test, subjects were instructed about the test procedure, and asked to assess their preferences in audio-only, visual-only and audio-visual conditions.

The responses obtained from the tests were then analysed statistically. Correlations between audio-only, visual-only and audio-visual preferences were examined, as well as differences in responses between different ages, genders and cultural groups. The principal components affecting audio-only, visual-only and audio-visual preferences were investigated through a principal component analysis. Furthermore, the degree of agreement among subjects in rating preferences for the three test conditions tested was evaluated using concordance analysis, and a hierarchical cluster analysis was also carried out. Finally, audio-only preferences were correlated with the acoustic/psychoacoustic parameters calculated from sounds including both water sounds and road traffic noise.

The findings obtained allowed identifying which water sounds and visual displays are preferred for improving relaxation in the presence of road traffic noise. Additionally, this also allowed investigating the relationship between acoustic/psychoacoustic parameters and preferences, in view of understanding the effect of sounds' physical properties on perception.

1.4.2 Semantic differential tests

A semantic differential test was carried out in view of evaluating the qualitative characterisation of the ten different waterscapes used. This consisted of mainly of semantic differential questions based on a five-point verbal scale, with nine attributes and antonymous adjectives, for each of the water sounds considered. This test was undertaken following the first part related to water features' preferences.

Results from the semantic differential test were examined through statistical analysis. The average scores obtained for each attribute were correlated with each other, and the principal components affecting water sounds' characterisation were identified using a principal component analysis. Furthermore, principal components were correlated with audio-only preferences of water sounds combined with road traffic noise, and stochastic relationships between audio-only preferences and semantic components/attributes were examined using logistic regressions.

The findings obtained allowed identifying the principal semantic components affecting waterscapes' perception, the relationship between semantic components/attributes and preferences of water sounds, as well as the correlations with acoustic/psychoacoustic parameters.

1.4.3 Categorisation and evocation tests

These tests were carried out in view of understanding the effect of categorisation (audio and visual) and evocation (audio) of water features on perception. All auditory tests were based on listening to water sounds played individually with road traffic noise, and then answering a questionnaire. Subjects were asked to indicate which type of water feature the sound made them think of (*waterfall, fountain, natural stream, none of these*), as well as to indicate if the water sound could be associated to a manmade sound (e.g. water falling into a drain/container or a tap) or rainfall. Evocation was also examined by asking the following open-ended question: "*If the sound evokes anything to you, please explain what it makes you think of*".

All of the above tests concentrated on the acoustical perception of the water sounds. In addition, one visual assessment was undertaken, as subjects were asked to rate the water features' displays as *manmade*, *natural* or *neither*. The categorisation of water features' displays was carried out through an online visual test where the ten displays corresponding to the waterscapes used in the audio-visual tests were shown.

Results obtained were correlated with responses from the perceptual preference tests, as well as the acoustic/psychoacoustic parameters calculated from the corresponding water sounds combined with road traffic noise.

The findings obtained allowed understanding how subjective categorisation and evocation properties of the water sounds can affect auditory and visual perception.

1.4.4 *Development of sound maps*

In order to develop sound maps for the water features tested, sound propagation models were used for each type of sound source considered (point or line). A prediction of sound pressure levels at different receiver positions was made by considering each water feature located in a grid of 20 m × 20 m. The propagation models included input data defining the sound power level of each water feature as well the directivity correction, and data related to attenuations occurring due to geometrical divergence, atmospheric absorption and ground effect.

The predicted sound levels were then used to identify acoustic areas with different levels of relaxation for each type of water structure tested. Three acoustic zones (‘water sounds dominant zone’, ‘optimum zone’ and ‘RTN dominant zone’) were defined in the research presented here by taking into account quantitative criteria. These zones were calculated for all the waterscapes considered, when these were used over different road traffic noise levels. This analysis was also made for water features operating under different flow rates, as well as combinations of different water features in the grid of study.

The findings obtained allowed evaluating which type of water feature is most effective in promoting relaxation under different road traffic noise levels, as well as identifying the optimal distances from the water feature where relaxation can be achieved. This also allowed revealing evidence-based solutions for the design of individual or combined water features which can be located in specific road traffic noise settings.

1.5 Outline of thesis

Chapter 2 initially provides an overview of water features, including a description of their different forms, origins and development throughout history; and the chapter also describes the landscape/architectural and engineering approaches for water features’ design. A review of previous works is then given, including general information about soundscape approaches. Finally, main findings that are relevant to the research presented in this thesis are illustrated and critically discussed.

Chapter 3 illustrates the methodology used for the research, including an initial overview of sound descriptors and background theory related to the methods. The water features examined are then illustrated in details. This is followed by the methodology used for the perceptual assessment of water features used over road traffic noise and the statistical methods used for data analysis. More detailed aspects of the methods used for each test are given in the following chapters.

Chapter 4 describes the main findings obtained from the audio-visual tests in terms of audio-only, visual-only and audio-visual preferences. The methods used for the laboratory tests as well as for the assessment of preferences are initially illustrated. Preference results are then discussed and correlations between preferences in uni-modal and bi-modal sensorial conditions are examined. Results obtained from a principal component analysis are also illustrated, as well as results obtained from a hierarchical cluster analysis. Finally, correlations between preferences and acoustic/psychoacoustic parameters are evaluated.

Chapter 5 presents the results obtained from the semantic differential tests. Methods are illustrated initially, followed by attributes' results and their correlations. Principal semantic components are then examined through a principal component analysis. Finally, correlations between semantic components/attributes of water sounds and audio-only preferences, as well as their corresponding acoustic/psychoacoustic parameters, are analysed.

Chapter 6 illustrates main findings obtained from the qualitative categorisation and evocation of water sounds. Results are initially presented in terms of sound categorisation (waterfall vs. fountain vs. stream), manmade water sounds evocation, as well as rainfall evocation. Additionally, the chapter illustrates results obtained from the qualitative "open-ended" descriptions of water sounds, as well as results obtained from the visual categorisation of water features' displays. Finally, sound categorisation and evocation are further examined through correlations with audio-only preferences and acoustic/psychoacoustic parameters of water sounds.

Chapter 7 presents sound maps of water features used over road traffic noise. A brief description of the relevant background is given initially, followed by illustrations of the methodology used. Results obtained from mapping water generated sounds are then presented for all the waterscapes considered in this research, as well as sound maps of acoustic zones for all the water features used over road traffic noise levels ranging between 40 and 70 dBA. Furthermore, sound maps are given for water features operating under different flow rates, as well as for combinations of multiple water features.

Chapter 8 illustrates a new framework of designable factors for the design of water features based on criteria related to a soundscape approach as well as architectural/landscape and engineering approaches.

Chapter 9 provides a summary of the conclusions, and it describes the impact of research and suggestions for future work.

Appendices A to D include the questionnaires used for laboratory tests (audio-visual tests, semantic differential tests and qualitative categorisation and evocation tests), while Appendix E shows the form used for visual categorisation of water features' displays. Appendix F provides results obtained from the "open-ended" descriptions of water sounds. Appendices G to M consist of sound maps of water features used over road traffic noise ranging between 40 and 70 dBA. Appendix N provides sound maps of acoustic zones for water features with different flow rates. Appendices O and P show sound maps of acoustic zones for multiple plain edge waterfalls (PEW) located in the grid of study at different positions when they are used over road traffic noise levels ranging between 65 and 70 dBA. Appendices Q to T show sound maps of acoustic zones for combinations of different water features used over road traffic noise ranging between 55 to 70 dBA.

CHAPTER 2
Literature Review

2.1 Introduction

In this chapter, the sound descriptors and theory related to the methods used are initially presented. This follows by giving an overview of water features, including a description of their different forms, origins and development throughout history. The principles and concepts applied to the design of water features are then illustrated based on landscaping/architectural and engineering approaches. In addition, a review of the previous works is given in order to point out the main findings that are relevant to the project presented here, as well as to identify the gaps to be filled in the literature. General information about the context of application of soundscape approaches, as well as differences between the noise control and soundscape approaches are then presented; and a brief introduction to the definition of 'soundscape', its development and research applications is given. Furthermore, the process of standardisation and the great institutional interest in soundscape applications are then illustrated. Additionally, main findings of studies focused on the acoustic use of water features are then presented with particular attention to the physical phenomenon of water generating sounds, the evaluation of the quality of water sounds, the effect of audio-visual interaction on perception, acoustical preferences and perceptual assessment of water sounds, and finally the masking properties of water features used over road traffic noise. A critical discussion is given for each section of this chapter, and conclusions are illustrated at the end.

2.2 Sound descriptors and background theory

2.2.1 Basic properties of sound

Sound is the transmission of vibrational energy through a solid, liquid or gaseous medium, and is due to the motion of a source (Long, 2006). As a wave propagates through a medium such as air, the air particles oscillate back and forth when the wave passes. In air, the sound wave is transmitted and propagated in the form of a longitudinal pressure fluctuation, as the particle motion is in the same direction of the wave propagation (Kang, 2007). Subjectively, sound represents the sensation produced by stimulating of the human organs of hearing when the vibrations transmitted through the air, with frequencies in the approximate range of 20 to 20,000 Hertz, are detected by the ear and then converted into electrical signal into the brain. The vibration of the ear drum is due to the compression waves propagating through the air, and the ear responds to the sound pressure, *p*, which is caused by the presence of a wave (Kang 2007) and measured in N/m^2, known as Pascal (Pa). From the threshold of audibility (2×10^{-5} N/m^2) to the threshold of pain (200 N/m^2), the acoustic measures vary over a wide range. The common practice is thus to express acoustic indicators in terms of level by using a more convenient parameter, the decibel (dB), that is based on a logarithmic scale.

2.2.2 Sound levels - Decibels

The sound pressure level, L_P, is the most commonly used indicator of acoustic wave strength and it correlates well with human perception of loudness.

$$L_P = 10 \log \left(\frac{p^2}{p_0^2}\right) = 20 \log \left(\frac{p}{p_0}\right) \quad (\text{dB re } 2 \times 10^{-5} \text{ Pa}) \tag{2.1}$$

where p is the root – mean – squared pressure (Pa) and p_0 is the reference pressure equal to 2×10^{-5} Pa.

The strength of an acoustic source is characterized by its sound power (W), expressed in Watts. Like other acoustic quantities, sound powers vary greatly, and a sound power level, L_w, is used to compress the range of numbers (Long, 2006).

$$L_w = 10 \log \left(\frac{W}{W_0}\right) \quad (\text{dB re } 10^{-12} \text{ W}) \tag{2.2}$$

where W is the sound power and W_0 is the reference sound power (10^{-12} W).

The sound intensity, I, is the average rate at which sound energy is transmitted through a unit area perpendicular to the specific direction (Long, 2006). The sound intensity level can be calculated as

$$L_I = 10 \log \left(\frac{I}{I_0}\right) \quad (\text{dB re } 10^{-12} \text{ W}/m^2) \tag{2.3}$$

where I is the intensity level (W/m^2) and I_0 (10^{-12} W/m^2) is the reference intensity or the minimum sound intensity audible to the average human ear at 1 kHz.

The classical acoustic equation of sound pressure level relating to sound power level outdoor is (Smith *et al.*, 1997):

$$L_p = L_w - 10\log S \tag{2.4}$$

where L_w is the sound power level (dB) and S is the surface through which sound propagates at a source-receiver distance r. This formula (2.4) shows as the sound pressure level radiated by a source, can be referred to the sound power level and is dependent on the distance between the source and the receiver (Fry, 1988). Additionally, this formula provides a convenient way to measure the sound power level of a source in a free or semi-free field by using measured values of sound pressure level at different distances from the source.

2.2.3 Outdoor sound propagation

The calculation of outdoor noise levels at large distances between source and receiver requires detailed consideration of several effects, including source characteristics, source-receiver distance, surface reflections and attenuations occurring along the propagation path from the source to the receiver.

If a point source located in free field conditions radiates sound energy in all directions equally, a sound wave propagates spherically and the sound intensity received at a certain location will be inversely proportional to the square of the distance (r) from the source in according to the inverse square law (Fry, 1988).

$$I = \frac{W}{4\pi r^2} \qquad (W/m^2) \tag{2.5}$$

This is equivalent to a reduction of 6 dB SPL with each doubling of the distance from the source (Kang, 2007). According to equation (2.4), the sound pressure level, which is radiated from a point source in the free field, can be then calculated as:

$$L_p = L_w - 10\,log(4\pi r^2) = L_w - 20\log(r) - 11 \qquad \text{(dB)} \tag{2.6}$$

When the point source is located close to a hard ground and reflections of the emitted sound occurs, this source radiates as a hemisphere and equation (2.6) becomes:

$$L_p = L_w - 10\,log(2\pi r^2) = L_w - 20\log(r) - 8 \qquad \text{(dB)} \tag{2.7}$$

In the case of line sources, these are one-dimensional sound sources such as roadways, which extend over a distance that is large compared with the measurement distance (Long, 2006). With this geometry the measurement surface is not a sphere but rather a cylinder with its axis coincident with the line source ($S = 2\,\pi\,d\,L$, where d is the radius of cylinder and L is the length). In this case, the maximum intensity is equal to

$$I = \frac{W}{2\pi r L} \qquad (\mathrm{W/m^2}) \tag{2.8}$$

For an ideal line source of infinite length in a free field, the sound pressure level can be determined assuming a cylindrical sound propagation, and can be found from

$$L_p = L_w - 10\,log(2\pi r L) = L_w - 10\log(rL) - 8 \qquad (\mathrm{dB}) \tag{2.9}$$

where d is the source-receiver distance (m), L is the length of the source (m) (usually referring to 1 m section) (Kang, 2007). Equation (2.9) shows that the SPL falls off at 3 dB with each doubling of the distance from the source. If a line source is located close to hard ground, the source behaves like a hemisphere and equation (2.9) becomes:

$$L_p = L_w - 10\,log(\pi r L) = L_w - 10\log(rL) - 5 \qquad (\mathrm{dB}) \tag{2.10}$$

In the case of sound that radiate from a planar surface, the variation of sound pressure levels with distance can be explained by using the Rathe method (Figure 2.1) (Smith *et al.*, 1997). Over the region close to the source, the radiated sound remains more or less

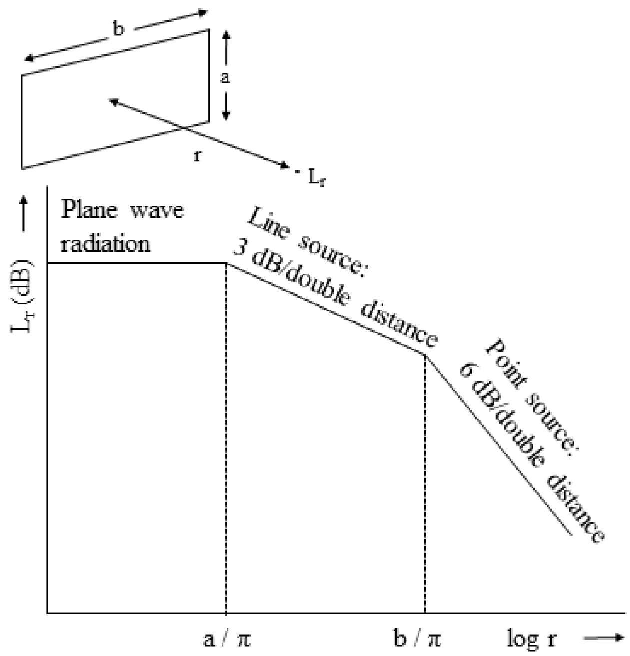


Figure 2. 1 Rathe method: the radiation of a finite planar source (Smith *et al.*, 1997).

constant. At great distances from the sound source, the wavefronts become spherical and thus the sound pressure level falls at 6 dB per doubling of distance. Between these two regions, the wavefronts become cylindrical, and the reduction of sound pressure levels is 3 dB per doubling of distance: this means that the source behaves as a line. Considering a finite planar source of height a and length b ($b > a$) (Figure 2.1):

if $r > b/\pi$ $$L_p = L_w - 20\log(r) - 11 \quad \text{(dB)} \tag{2.11}$$

if $a/\pi < r < b/\pi$ $$L_p = L_w - 10\log(r) - 8 \quad \text{(dB)} \tag{2.12}$$

where equation (3.17) assumes that L_w is defined in dB/m re 10^{-12} W (Long, 2006).

2.2.4 Auditory perception

The human ear is a sensitive and complex organ (Long, 2006). The perception of sound is a function of the hearing system's mechanism. The ear can be subdivided in three parts, termed the outer ear, the middle ear and the inner ear. The outer ear mainly works to collect sound and direct it to the tympanic membrane (Fastl and Zwicker, 2006). The middle ear that is located behind the tympanic membrane works with the main function of transferring vibrations from the outer ear (low density medium) to the inner ear (high density fluid present in the cochlea). As a pressure wave moves through the cochlea it induces a ripple motion in the basilar membrane and for each frequency there is a maximum displacement in a certain region (Long, 2006). The cochlea contains fine hair-like cells, termed *organ of Corti*; the movement of the fluid within the inner ear stimulates these cells which then transmit electrical discharges to the auditory nerve. Finally, the auditory nerve conducts the electrochemical impulse to the brain whereby we perceive these signals as sound (Long, 2006).

Frequencies in the audio range are from about 20 Hz to 20 kHz, and can cover a wide range of sound pressure levels. In many applications involving acoustic measurements, the final sensor is the human ear. For this reason, acoustic measurements usually attempt to describe the subjective perception of a sound by this organ. Instrumentation devices are built to provide a linear response, but the ear is a nonlinear sensor. Therefore, special filters, known as weighting filters, are used to account for the nonlinearities. The development of weighting filters helped to overcome this problem by using weighting corrections which can be added to the original dB value at each frequency (Long, 2006).

The corrections commonly used are different weighting scales termed as A, B, C, and D. The A weighting scale corresponds roughly to the inverse curve of the 40 phon equal loudness contour (refer to section 2.2.5 for definitions and details of loudness). The A-weighted level (dBA) is the most common single number measure of loudness, as it has shown to correspond most closely to the ear response. The B scale corresponds to the inverse curve of the 70 phon loudness contour, but it is rarely used in practice. The C scale is linear at most frequency, and levels measured in dBC can be compared to dBA levels to identify whether or not the noise measured is dominated by low frequencies. The D-weighting corrections are specifically used for aircraft noise measurements. In the research presented here, the A and C weighting filters were considered, and the difference in level between L_{Ceq} and L_{Aeq} was used as indication of low frequencies contents .

The most common descriptor used is the equivalent continuous noise level, $L_{eq,T}$. It represents the sound pressure level of a steady sound that has the same energy as the fluctuating sound in question over a given period, T, and can be calculated as (Long, 2006)

$$L_{eq,T} = 10\log\left(\frac{1}{T}\int_0^T \frac{p^2(t)\,dt}{p_0^2}\right) \tag{2.13}$$

where p_0 is the reference pressure 2×10^{-5} Pa. The equivalent continuous noise level is widely used in standards and regulations and is often based on A-weighted levels which are more representative of loudness perceived by individuals.

In order to consider the time-varying character of environmental noise, statistical sound descriptors have been also adopted by the noise community. In general, the statistical percentile level L_n represents the sound level exceeded n% of the time. The common descriptors used are L_{10}, L_{50} and L_{90}. The percentile level L_{10} is the sound level exceeded only 10% of the measurement time, and this provides a good measure of the maximum sound levels caused by intermittent or intrusive noise such as road traffic noise. L_{50} is the sound level that is exceeded 50% of the measurement time period, and it represents the median sound level. L_{90} is the sound level exceeded 90% of the time, and this has been generally adopted as a good measure of the background noise. Additionally, the difference between L_{10} and L_{90} can be used as indicator of temporal variations in level.

Additionally, in calculating some measures of noise, sound pressure levels have a standard *fast* response time, which corresponds to a time constant of 0.125 s in order to approximate the integration time of our hearing system (WHO, 1999). Thus, all measurements of sound pressure levels and their variation over time should be made using the *fast* response time in order to provide sound pressure measurements more representative of human hearing (L_{Fmin} and L_{Fmax}, maximum and minimum levels over a fast time constant) (WHO, 1999). Sound pressure meters may also include a *slow* response time with a time constant of 1 s, but its sole purpose is that one can more easily estimate the average value of rapidly fluctuating levels (L_{Smin} and L_{Smax}, maximum and minimum levels over a slow time constant). Many modern meters can integrate sound pressures over specified periods and provide average values. It is not recommended that the *slow* response time be used when integrating sound level meters are available (WHO, 1999).

2.2.5 Psychoacoustics

Psychoacoustics is the scientific field of choice to bridge the gap between physical and subjective evaluations (Fastl, 2006a). Psychoacoustic magnitudes such as loudness, sharpness, roughness, fluctuation strength and pitch are important factors that have to be considered in sound quality evaluation.

*Loudnes*s is a subjective measure related to the hearing system and is a function of the amplitude and frequency of vibrations. Loudness is therefore a quality of the sound: it is dependent on the number of nerve impulses reaching the brain in a given time, but a variation with the frequency content of sound occurs when those impulses come from different parts of the cochlea (Fastl and Zwicker, 2006).

Sharpness can be defined as the hearing sensation related to frequency (Fastl and Zwicker, 2006). It refers to the sensation of a sharp and high-frequency sound, and is the comparison of the amount of high frequency energy to the total energy. High frequency components result in higher sharpness measurements (Fastl and Zwicker, 2006). Adding a right amount of sharpness to a sound can make it to be powerful, whilst too much sharpness can give to this sound a feature of aggressiveness (Fastl and Zwicker, 2006). Sharpness is an indication of the spectral balance between low and high frequencies: the more high frequencies a signal contains, the higher its sharpness is (Kang, 2007). Examples of sharp sounds include a gunshot or sharpening a knife.

Roughness can be qualitatively described by defining the Latin word “asper” as “rough” (Fastl and Zwicker, 2006). Roughness is a complex effect which quantifies the subjective perception of rapid (15-300 Hz) amplitude modulation of a sound, and depends on the temporal variation of sounds. Qualitatively, roughness may be described as ‘grating’ (Kang, 2007). A rough character of a sound usually causes an unpleasant hearing impression, and examples of rough sounds include the humming of an electric razor or a sewing machine (Kang, 2007).

The magnitude *fluctuation strength* is a similar to roughness as being a measure of the amplitude modulation, and depending on the temporal variations of sounds (Fastl and Zwicker, 2006).

Pitch is a measure of the relative content of pure tones in a signal, so pitch sensation (*pitch strength*) refers to the subjective impression of the frequency content of a sound. It depends on the human perception of how high or low is a tone sound (Long, 2006).

2.2.6 Masking

The masking effect occurs when a signal is rendered unintelligible or inaudible by a simultaneous sound that exceeds a certain level (Kang, 2007). Masking is defined as ‘a process by which the threshold of hearing for one sound (target sound or maskee) is raised by the presence of another (masking sound or masker) sound (Fastl and Zwicker, 2006) (Long, 2006). (Kang, 2007). Masking effects of a target sound by a masking sound can be total, making the target sound inaudible, or partial, making it less loud (Scharine *et al.*, 2009). The masking sound can also be of two types: *energetic* maskers which physically affect the audibility of the target sound, and *informational* maskers which have masking capabilities due to their similarity to the target sound (Fastl and Zwicker, 2006). Energetic masking (EM) is related to sound energy and its distribution in frequency and time domains, and there are two basic forms of this type of masking: simultaneous masking and temporal masking (Fastl and Zwicker, 2006). Simultaneous masking occurs when a masking sound is present throughout the duration of the target sound and it is the most effective form of energetic masking. The amount of masking is dependent on the sound intensity of the masking sounds and its spectral proximity to the target sound (Fastl and Zwicker, 2006). Temporal masking is caused by sounds that are not simultaneous with the target sound, and is divided in forward (post-stimulatory) masking and backward (pre-stimulatory) masking (Fastl and Zwicker, 2006). Forward masking occurs when a signal is masked by a sound preceding it, meaning that the target sound is played after the end of the masking sound. Backward masking appears when the target sound is presented just before the masking sound (Fastl and Zwicker, 2006). Additionally, informational masking (IM) is defined as the process occurring when one stimulus is masked by one another and this effect cannot be explained by the presence of energetic masking (Durlach *et al.*, 2003) (Fastl and Zwicker, 2006). In other words, this is the masking caused by the characteristics of the masker other than its energy. Informational masking is caused by two main aspects which are the similarity between the masking sound and the target sound and the variability (uncertainty) of the masking sound (Durlach *et al.*, 2003). It has been demonstrated that the decrease in the degree of similarity between the target sound and the masking sound reduces substantially the amount of informational masking affecting the target sound (Fastl and Zwicker, 2006).

2.2.7 Methods used for sound quality

Blauert and Jekosch (1997) defined sound quality as the characteristics that acoustic emissions should have in addition to acoustic levels (Fastl, 2006). In sound quality engineering, for each sound, the "right" recipe has to be found on how to mix the different hearing sensations, thus to arrive at the desired sound (Fastl, 2006a). Sound quality is defined as the "adequacy of a sound in the context of a specific technical goal and/or tasks" (Kang, 2007). Sound quality evaluation depends on stimulus-response compatibility which is the functional aspect of a sound, the pleasantness of a sound based on the overall impression resulting from individual preference and experience, and the ability to identify sounds or sound sources making people aware of what is happening around (Kang, 2007). Sound evaluation is usually based on physical measurements but also depends on the judgment of the human hearing system.

It should be recognised that the effects of auditory stimulation involve not only a quantitative judgment of sensations and the subsequent perception of the acting stimulus, but also an emotional judgment of the aesthetic value of stimulus (beauty) and an assessment of the degree of the listener's satisfaction (utility) (Fastl and Zwicker, 2006). These types of judgments are together called the sound quality judgments and can be evaluated by using different methods that have proven to be successful in psychoacoustics, such as the method of "random access", the method of "magnitude estimation" and the method of "semantic differential" (Fastl, 2006b). The method of "random access" allows obtaining quick information, whether a product sounds better than the product of a competitor (Fastl, 2006b). The method "magnitude estimation" can give an indication, how much the sound quality of products differs, while the method of "semantic differential" can give an indication on how sounds can be perceptually associated and defined by a verbal scale. In this section details are described only for the semantic differential method, as this was the only method used for the qualitative categorisation of water sounds tested in the research presented here (detailed information can be found in Chapter 5).

Semantic differential is a method that can be used to test the most suitable sound for a specific goal and/or task (Osgood, 1952). Subjects are asked to express their own opinion in term of impression of the overall soundscape based on adjective scales which represent specific connotative meanings of environmental sounds such as loud-soft, pleasant-unpleasant, comfortable-uncomfortable. A numerical rating scale is also possible to refer to each index (adjective). This technique is the most suitable method which allows to connect subject's feeling at both linguistic and psychological levels with sound sources in an acoustic environment (Kang, 2007). An example of a soundscape evaluation form used by Kang and Zhang (2010) in a soundwalk carried out in Sheffield is shown in Figure 3.7. A group of antonymous adjectives represents the multiple dimensions of perception (Kang, 2007). Each pair of adjectives defines the two ends of a multiple point scale. Different numerical rating scales have been used in acoustic – social surveys with the aim of evaluating sound perception by using a semantic differential analysis. A *three point numerical scale* (e.g. 1, favourite; 2, neither favourite or annoying; 3, annoying) has been used in soundscape research to evaluate the subjective preference of a single sound (Kang, 2007) as well as to identify the recognised sounds and to classify the sound preference as an indication of wanted or unwanted sounds on the case study (Yang and Kang, 2005a). The *five rating scale* has often been employed in aesthetic preference research (Kaplan, 1987) as well as in soundscape research with the aim of evaluating the sound environment (e.g. 1, very quiet; 2, quiet; 3, neither quiet nor noisy; 4, noisy; and 5, very noisy) (Yang and Kang, 2005b) (Fiebig *et al.*, 2010) (Kang and Zhang, 2010) and the acoustic comfort (e.g. 1, very comfortable; 2, comfortable; 3, neither comfortable nor uncomfortable; 4, uncomfortable; and 5, very uncomfortable) (Yang and Kang, 2005b) in urban open public space through soundwalking. It has been also used to evaluate the subjective preference of sound levels (Kang and Zhang, 2010) as well as preferences of an urban soundscape with combined noise sources and water sounds (Jeon *et al.*, 2010). A *seven point numerical scale* (e.g. 3, very agitating; 2, fairly agitating; 1, little agitating; 0, neutral; -1, little calming; -2, fairly calming; -3, very calming) has been adopted in the evaluation of the overall soundscape (Kang and Zhang, 2010) (Guillén and López Barrio, 2007) (Jeon *et al.*, 2011). According to the ISO/TS 15666, specifications for wording and scaling of questions on annoyance could be taken into account for socio-acoustic surveys (ISO/TS

15666, 2003). Both a *five point verbal scale* (not at all; slightly; moderately; very; extremely) and an *eleven point numerical scale* (0, not at all; 10, extremely) have been indicated as a good mean for the evaluation of noise effects in terms of annoyance. According to the ISO/TS 15666, both the five point verbal and eleven point numerical scales can be used for quantitative analysis of urban soundscape in terms of annoyance, as pointed out by Jeon *et al.* (2010). The *eleven point numerical scale* has been also adopted in soundscape research to obtain the subjective preference for the physical conditions of urban environments (e.g. "What number from 0 to 10 best shows how much you prefer each item?" item 1, Landscape; item 2, Lighting; item 3, Fragrance/odour; item 4, Reverberation) (Schulte-Fortkamp *et al.*, 2010).

The *paired comparison* method was developed by the American psychologist Louis Thurstone (1927), who used it to investigate a wide range of psychological attributes (e.g. 'seriousness of crime') (Bramley, 2007). The paired comparison method is used to measure individuals' preference orderings of items presented to subjects as discrete binary choices (Brown and Peterson, 2009). A paired comparison is simply a binary choice. With the method of paired comparisons, a set of stimuli, or items, is judged, usually by presenting all possible pairs of the items to each respondent who chooses for each pair the item that better satisfies the specified choice criterion (for example, preferred, more relaxing, more beautiful) (Brown and Peterson, 2009). The paired comparisons produce ordinal data, and for this reason it was considered an appropriate method for ranking preferences in the research presented here. This method has often been used in soundscape research (You *et al.*, 2010)(Jeon *et al.*, 2010) (De Coensel *et al.*, 2011) (Galbrun and Ali, 2013), and was preferred to rating scales because of its simplicity and greater accuracy (Mantiuk *et al.*, 2012): paired comparisons guaranteed a definite and more accurate ranking order through forced choice, unlike rating scales that would have allowed subjects to give identical scores to different waterscapes. Further details can be found in Chapter 4.

2.3 Effects of noise

Environmental noise is defined as unwanted or harmful outdoor sound that can affect the physiology of people, and it can also induce psychological and cognitive performance effects on individuals (European Environment Agency, 2014). Noise is associated with many human activities, but road, rail and air traffic noise have the highest impact on human well-being. This is particularly a problem for the urban environment; about 75%

of Europe's population lives in cities, and traffic volumes are still on the rise (European Environment Agency, 2014). Country reviews show that the number of complaints related to environmental noise is increasing in many European countries (European Environment Agency, 2014). The EU Green Paper Future Noise Policy states that around 20% of the EU's population suffer from noise levels that health experts consider to be unacceptable, i.e. which can lead to annoyance, sleep disturbance and adverse health effects (European Environment Agency, 2014). The quantification of the related disease from environmental noise is a challenge for policy makers. Noise exposure not only leads to sleep disturbance, annoyance and hearing impairment, but also to other health problems such as cardiovascular disorders (European Environment Agency, 2014). Additionally, the WHO (1999) recommended guidelines values of noise limits relating to critical health effects derived from noise exposure in outdoor environments (Table 2.1).

The potential physiological effects of environmental noise consist of hearing impairment, cardiovascular problems, physiological stress and sleep disturbance. Hearing loss is related to a variety of causes such as inflammation of the ear canal or Eustachian tube, blockage within the ear canal; and it is also connected with aging and noise-induced. Cardiovascular problems include increases in heart rate and blood pressure, and these can be related to noise exposure. The effects of indoor and outdoor noise exposure induce disturbed sleep. Acute sleep disturbances affect the subjective wellbeing as well as qualitative or quantitative performance (WHO, 1999).

Environmental noise exposure induces psychological problems depending on environmental conditions and individual subjectivity of people. *Annoyance* is a crucial effect of noise and is used to identify the psychological effects of noise. Noise annoyance is defined as a feeling of discomfort which is related to noise exposure and can lead to stress (WG2 Europen Communities, 2002). Working Group 2 Dose/Effect, formed by the European Commission in 1998, recommended that the percentage of people annoyed (*%A)*, or the percentage of people highly annoyed (*%HA)* should be used as descriptors

Table 2. 1 WHO recommended guidelines for community noise in specific environments (WHO, 1999).

Specific environment	*Critical health effect(s)*	*L_{Aeq} (dB)*	*Time-base (h)*	*L_{Amax} (dB) (fast)*
Outdoor living area	Serious annoyance, daytime and evening	55	16	—
	Moderate annoyance, daytime and evening	50	16	—

of noise annoyance in a population (WG2 Europen Communities, 2002).

The widespread assumption of a relationship between noise exposure and human cognitive performance provides an explanation for noise effects on performance, both positive and negative. Performance is a function of the arousal level of an individual. Arousal theory indicates that arousal mobilizes and regulates the human stress response (Staal, 2004). This response is related to physiological, cognitive, behavioural and emotional dimensions of an individual. Changes in performance are a function of changes in arousal: a rise in arousal may give a rise in performance if it corresponds to a movement from a low to a medium level of arousal; but the same rise in arousal will give a fall in performance if arousal level is already medium (Suter, 1989). Noise exposure increases the arousal level of an individual, facilitating a concomitant increase in performance (e.g. for simple task as repetitive manual task) up to a point where over–arousal occurs, resulting in corresponding decrements in performance (e.g. attentional and vigilance tasks) (Suter, 1989). Although the research presented in this thesis is within the context of relaxation, the background related to the cognitive performance effects of noise exposure are illustrated here due its relevance as this could be considered by future research.

2.4 Water features

2.4.1 Water as symbol and crucial element for life

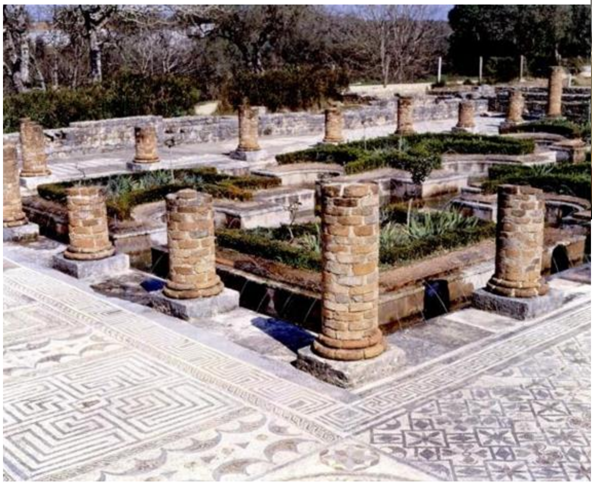
“Water is far from being just a designers resources or material” as stated by Dreiseitl and Grau (2009), it represents a crucial element to survival and has a symbolic meaning. For humans there is a hierarchy of water use ranging from survival water needs (drinking and cooking), to maintenance water needs (personal washing, washing clothes, cleaning buildings, growing food and waste disposal) and lasting water needs (business and recreation) (Dykstra, 2007). In addition, water, the original life element, has the most splendid symbolism: rain, a stream, a fountain, a river, a waterfall, the sea, each makes its unique sound but all share a rich symbolism (Schafer, 1994). They speak of cleansing, of purification, of refreshment and renewal (Schafer, 1994). For example, to Chinese Feng Shui it represents a good “chi” (life energy), and in Christianity it means cleansing. The Chinese Feng Shui, translated as “wind-water”, is a Chinese system of beliefs that aims at harmonising everyone with the surrounding environment. Feng Shui points out that water in the home, garden and work place brings calmness and good fortune. Water’s beauty is in its fluidity, transparency and reflexiveness (Dykstra, 2007). For centuries water has been an important part of lives creating a feeling of calmness and also providing an important role in architectural design. Integrating water into architecture is to make a connection between the two separate aspects of water, water as an essential element and water as entertainment.

2.4.2 Brief overview on origins and history

Throughout history, water features have been used for their aesthetic value, being very popular for their visual attributes, and for their contribution to the stimulation of other senses (Brown and Rutherford, 1994). Environmental sounds such as water sounds, played an important role in landscaping and gardening of ancient cultures (Carles *et al.*, 1992). In Egypt, water has dictated the shape of gardens and the pattern of life from the earliest times (Hopwood, 2004). The central feature of an ancient Egyptian garden was usually the pool, often for fish but also for pleasure (Figure 2.2(a)). Water both inside and outside temples was also a necessity in the daily ritual of religious life. Temples were the homes of the Gods and a pool was necessary for their refreshment (Hopwood, 2004). Hopwood (2004) stated that water features within architectural structures probably originated in Greece and Asia Minor, when water springs were enclosed to preserve their purity and were decorated as holy places. In addition to provide drinking water, water features were used for decoration and to celebrate their builders. In ancient Rome (8th century BC to 5th century AD), water was venerated as a gift from God and fountains were decorated with bronze or stone masks of animals or heroes. Proximity to water was considered to be vital for health and respite from daily cares and the building of aqueducts and reservoirs throughout the Empire for both utility and public pleasure in locations such as Conimbriga in Portugal (Figure. 2.2(b)) became one of the defining features of the Roman world.

By the 13th century AD, a mix of Persian and Islamic cultures gave a contribution to the definition of a new garden style demonstrated by the construction of the Alhambra, in Granada, Spain. Moorish and Muslim garden designers used fountains to create miniature versions of the gardens of paradise by using the delicate sound of running water carefully conveyed by a system of channels distributed through the garden (Carles *et al.*, 1992). Furthermore, water jets were added to the Granada's gardens to amplify water acoustics and visual effects as shown in Figure 2.2(c). In the Renaissance period (14th to 17th century), the idea of fountains like architecture and works of art originated in the

(a) Tomb painting showing an Egyptian garden in Thebes (Hopwood, 2004).



(b) Roman garden at Conimbriga, Portugal (Hopwood, 2004).

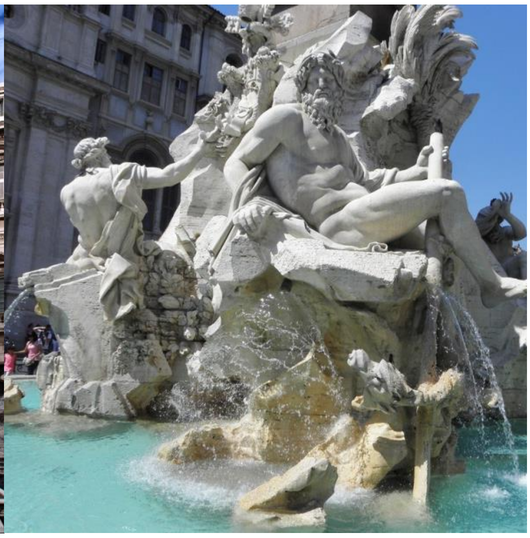
(c) General Life building, Alhambra, Granada, Spain.

Figure 2.2 Water features as essential elements in gardens from earliest time.

designer's mind, revealing a need to hold the attention of viewers by designing water features as a result of harmonizing aesthetic goals with technical considerations. In particular, the potential of fountain design was developed in Italy, especially Rome.

During the Italian Baroque period, fountains became complex compositions of basins, sculpture, and water displays. Rome is noted for its many fountains of baroque design, notably the Barcaccia Fountain (1626-1629) in Piazza di Spagna and the Cinque Fiumi Fountain (1648–1651) in Piazza Navona by Giovanni Bernini, and the Trevi fountain (completed in 1762) by Niccolò Salvi (Figure 2.3). Such fountains dramatized the rebuilding of the city, its squares, and its churches, done under papal direction. In addition

(a) Barcaccia Fountain, Piazza di Spagna (Credit: Sovraintendezaroma.it).



(b) Trevi Fountain (Credit: Flickr). (c) Cinque Fiumi Fountain, Piazza Navona (Credit: Flickr).

Figure 2.3 Baroque fountains in Rome, Italy.

to these public fountains, the idea of villa garden fountains was developed in Italy and represented by the Villa D'Este (1549) in Tivoli. This villa shows a spectacular design of cascades and upward jets on the hillside where it is located. Another example of ornamental fountains is the Gardens of Versailles (1661) in France by André Lenôtre. King Louis XIV of France used fountains to illustrate his power over nature (Dykstra, 2007). In modern ages (20th to 21st century), there is a long history of the use of water in and around buildings. Le Corbusier celebrated the triumph of running water by placing a sink in the foyer of Villa Savoye (1928-1930) and the roof solarium feels like the deck of a ship (Figure 2.4(a-c)) (Dykstra, 2007). Wright's sense of water resulted in the extraordinary exposition of water and building in the Fallingwater house (1935-1937) where nature integrates perfectly with the architecture (Figure 2.4(d)) (Dykstra, 2007).

(a) Villa Savoye, Le Corbusier, Paris, France (Credit: Architektur Lexikon).

(b) Roof solarium of Villa Savoye, Le Corbusier (Credit: Flickr).

(c) Sink in the foyer of Villa Savoye, Le Corbusier (Credit: Flickr).

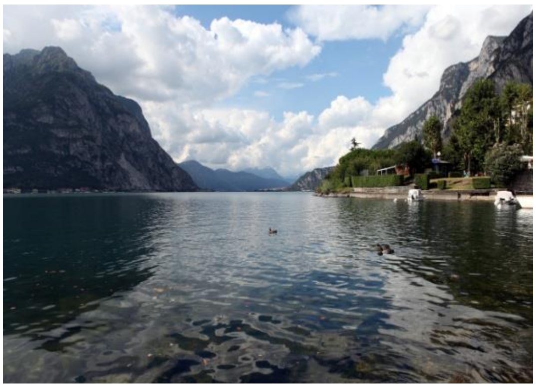
(d) Fallingwater House, Wright, Pennsylvania, USA (Credit: Flickr).

Figure 2.4 Integrating water with architecture in modern ages.

In the next section, definitions of water features are given based on different types found in nature.

2.4.3 Defining water features

Water features can be classified in two types: still and moving water. Still water refers to a flat, static and quiet water body such as ponds, lakes or pools. On the other hand, moving water refers to flowing and falling water, such as streams, waterfalls and cascades. Flowing water refers to “water flowing downward, along, over, and through various surfaces and forms” (Booth, 1989). Falling water refers to water dropping downward and over specific heights, whilst jets refers to water “created by forcing water up into the air



(a) Lake Como, Italy (Credit: Flickr).

(b) Small stream.

(c) Niagara falls, Canada (Credit: Flickr).

(d) Natural pond (Credit: Flickr).

Figure 2.5 Examples of water features found in nature.

through a nozzle in defiance of gravity" (Booth, 1989). Examples of water features can be found in nature, as shown in Figure 2.5. However, these can be also defined on the basis of a design viewpoint, as illustrated in the following section. Water features have been classified by designers in two main categories, such as *flat and static body of water* and *moving water*, as shown in Table 2.2.

A *flat and static water body* can be found in the form of either a pool or a pond. *Pool* is a term used for a body of water of any size placed in a hard and well-defined constructed container (Booth, 1989). This can be found in different geometric shapes with no limitations to the symmetry and forms (triangular, circular, square, etc.). The shape of the pool used in design depends on the setting and other design elements of form and character, but the most important design aspect is that a pool appears to be not natural (Booth, 1989). Therefore, designers indicated that this feature is most appropriated to be used in places where the expression of humans controlling nature is required such as in urban spaces where hard planes and edges predominate. This could also be used in outdoor environments as a plane of reflection for the sky and/or nearby elements. The second general type of flat and static water is the *pond*, which is generally designed to

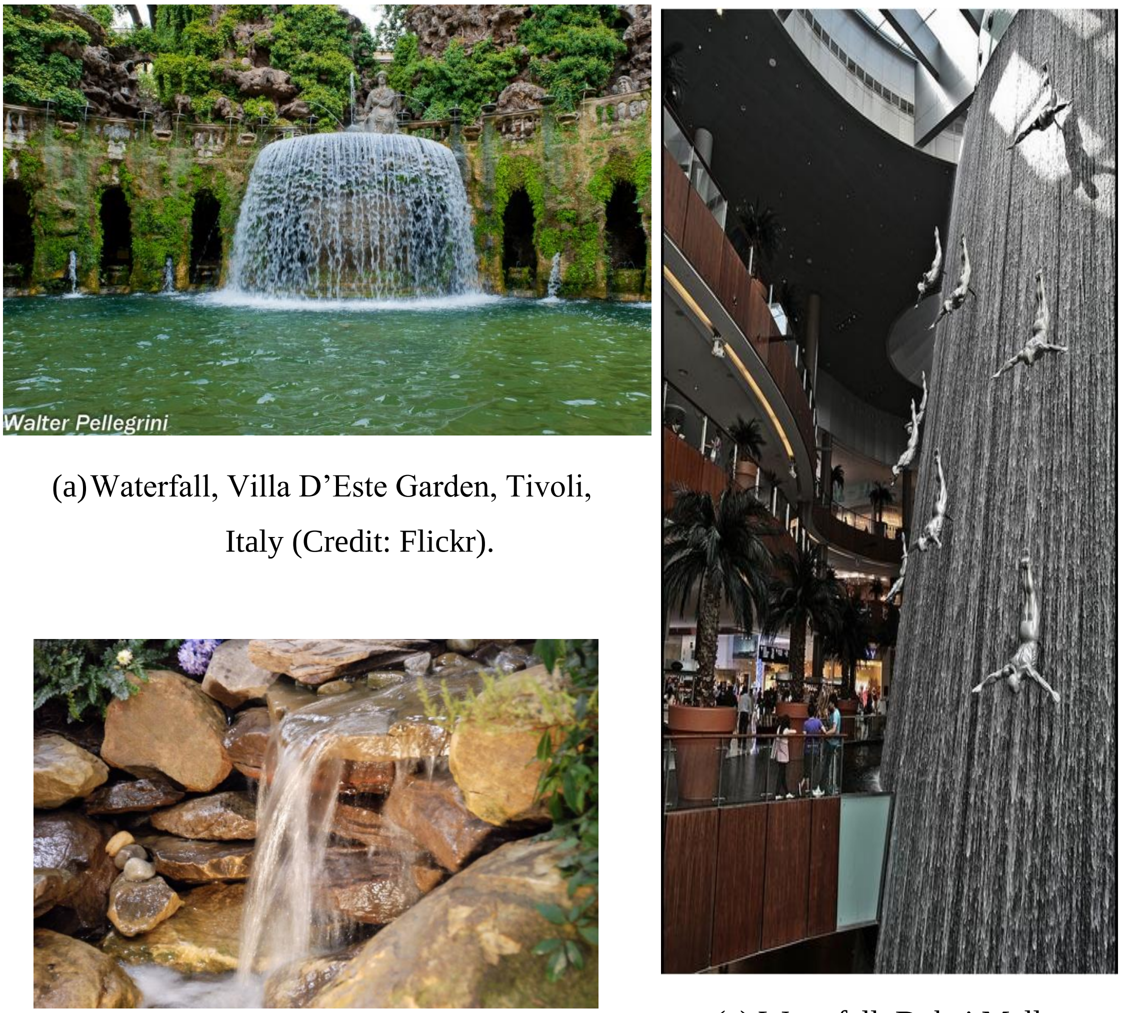
Table 2.2 Defining water features using a design approach.

Category	Sub-category	Type
Flat and static water body	-	Pool Pond
Moving water	Flowing waters	Water moving thorough a channel
	Falling water	Free-fall Obstructed flow Sloped fall
	Fountain jet	Upward fountain jet Downward fountain jet Combinations of jets
Combinations of moving and static water	-	-

appear natural or semi natural with a shape defined as free-form or curvilinear. This feature is mostly appropriated to be located in rural or park-like settings (Booth, 1989).

Among moving water bodies, *flowing waters* include any moving water confined to a well-defined channel. The behaviour and characteristics of flowing water depend on the volume of water, steepness, the channel size and properties of channel bottom and sides (Booth, 1989). The second form of moving water is *falling water* that can be classified as *free-fall, obstructed flow* and *sloped fall*. The *free-fall water* refers to water dropping from one elevation to another in an uninterrupted manner and its character depends on the volume and velocity of flow, the height of fall, the edge condition, the impact surface and the characteristic of the collection pool such as the depth of water and presence of hard surfaces (Booth, 1989) (Brown and Rutherford, 1994). On the other hand, *obstructed flow* indicates water striking various obstacles or planes while dropping between two elevations (Booth, 1989). These categories includes waterfalls for which different edge conditions such as a plain edge, a sawtooth edge and an edge made of small holes, can allow designing various water structures. This type of water feature can be used in outdoor environments (urban squares or gardens and parks), as well as in indoor space such as hotels' lobbies (Figure 2.6).

Another type of *falling water* is the *sloped fall* which refers to water dropping along and down a steeply sloped surface (Booth, 1989). This is similar to flowing water but occurs on a steeper slope in smaller controlled volumes. Cascade structures are included in this category and are increasingly common in parks and garden. These consists of water flowing over a series of steps with either constant or variable vertical drops and horizontal



(a) Waterfall, Villa D'Este Garden, Tivoli, Italy (Credit: Flickr).

(b) Waterfall/ cascade in home garden (Credit: Flickr).

(c) Waterfall, Dubai Mall, Dubai (Credit: Flickr).

Figure 2.6 Examples of designed waterfalls for outdoor (a)-(b) and indoor (c) spaces.

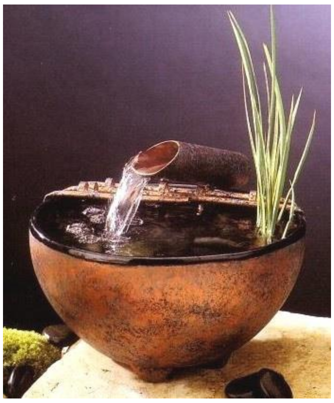
extensions of the whole structure from centimetres to metres (Brown and Rutherford, 1994). Different cascade structures can be designed by varying the height of the drops, the volume of water flow and the surface on to which the water falls at each drop (Brown and Rutherford, 1994). Additionally, a pump and motor system is required to recycle the water falling into the basin.

The third type of moving water is the *fountain jet*. The word *fountain* comes from the Latin term "fons" or "fontis", meaning "source" and represents a natural spring or the actual jet or spray of water. The jet and basin type fountain consists of a simple basin or an ornamental structure from which water emerges in a variety of artistic shapes (Hopwood, 2004). It includes single or multiple nozzles which pump water into the air,

(a) Upwards jets fountains, Villa D'Este, Tivoli, Italy (Credit: Flickr).

(b) Upward jets fountain located in indoor space (Credit: Flickr).

(c) The Hundred fountains, Villa D'Este, Tivoli, Italy (Credit: Flickr).



(d) Fountain for indoor or outdoor home environments (Credit: Flickr).

(e) The Ross Fountain, Princes Street Gardens, Edinburgh, UK (Credit: Flickr).

(f) Fountain in San Pietro Square, Rome, Vatican City (Credit: Flickr).

Figure 2.7 (a)-(f) Examples of upward and downward fountain jets and combination of jets located in indoor and outdoor spaces

whilst the falling water is collected in a basin. Different types of fountains can be defined on the basis of water flow:

- ✓ *Upward fountain jets* in Figure. 2.7 (a)-(b).
- ✓ *Downward fountain jets* in Figure 2.7 (c)-(d).

- ✓ *A combination of upward and downward jets* in Figure. 2.7 (e)-(f).

Different fountain types can be designed by varying the types of nozzle (narrow jet or large jet or foam effect or multiple jets nozzle), the water flow rate, the height of the jets and their fall, the number and positions of jets, the type of surface on to which water falls (e.g. water, concrete, boulders and stones) and the depth of the collecting pool (Brown and Rutherford, 1994). Almost all fountain jets are used as focal points in a design composition based on their verticality and interplay with light (Booth, 1989).

Most fountains are placed in a quiet, static body of water so that they can be fully appreciated against a neutral setting (Booth, 1989). This type of water features can be designed and installed in outdoor as well as indoor environments, as shown in Figures 2.7 where different examples of downward and upward jet fountains are given.

2.4.4 Designing water features

<u>Landscaping/architectural design</u>

The design of water features based on a landscaping/architectural viewpoint aims at using aesthetic and technical functions of water to provide visual enjoyment (creating an area that is a source of natural beauty), focal points (special interest areas that attract attention), native habitat (areas for wildlife conservation and management), recreational opportunity (areas for swimming, boating, fishing), retention ponds (on-site storm water retention) and irrigation reservoirs (a help to reduce the demand for potable water resources) (Booth, 1989) (Dreiseitl and Grau, 2005) (Downing, 1977) (AMC, 1999) (Zimmermann *et al.*, 2011). Water can be prestigious or symbolic, depending on how it is applied as a design element (Lohrer, 2008). Market fountains define the centre of a city; shopping centres lure customers with playful water features, and waterfalls cascading down the facades of office complexes signal the importance of the institutions within (Lohrer, 2008). Visually, water might be used in outdoor environments as a flat, reflective element to suggest tranquillity and contemplation; as a moving, flowing element to provide activity and sound; or as vertical fountain jets as accents and focal points (Booth, 1989). Several basic factors should be considered in designing water features, and these include (Figure 2.8):

- ✓ The characterisation of physical and technical properties: type of layout (e.g. fountain, waterfall, jets, cascade), the size of water feature (flow rate, height of water features), type of flow (jets, flowing water, still water or falling water), finishing materials and impact surfaces.

✓ Considering the environmental conditions for both indoor and outdoor installations: the wind exposure (e.g. the wind for outdoor fountains or ventilation systems for indoor fountains), operating temperatures (e.g. an outdoor fountains that will be operated for extended periods during the winter in areas subject to freezing), in some case, the humidity for both indoor and outdoor installations (e.g. indoor fountains located in confined interior spaces may elevate air humidity to uncomfortable levels), and the evaluation of ambient noise (i.e., undesirable background noise).

✓ Defining aesthetic and functional criteria: the shape and height of the visual elements according to the designer's aesthetic intent, using water features as focal point to draw the attention of viewers in urban or landscape settings, preservation and promotion of native habitat when using water as a design element in landscape or rural settings, considerations of the points from which the water feature will be viewed and the evaluation of the intended use of the surrounding spaces.

Among designable factors, considerations on acoustic aspects of water sounds have been recognised as important elements in landscape design, but these refer to water generating sounds only as effects of the visual design. A first attempt was made by Booth (1989) who gave a brief description of different sound effects based on the type of water feature, but merely related to a qualitative analysis. In this work, f*alling water* is described as a sharp splattering sound. When water falls into a pool/basin at the base of the fall, part of the movement of the fall is absorbed by the pool/basin so that, the amount of splashing is slightly less than when it falls on a hard surface. Water falling into water generates a deeper sound that is fuller-bodied rather than the one produced by water falling on a hard surface. Sounds originated from fountain jets depend on the type of nozzle considered. A *single-jet* produces a distinct sound due to the falling water of the jets striking the surrounding water. Sounds from a spray jet (produced by many narrow water "streams" that result from water being forced through a nozzle with many small openings) a "soft hiss", whilst aerated jets generate sounds similar to a single jets with the only difference that the opening nozzle in the aerated jet is larger so that it produces more water's turbulences.

<u>Engineering design</u>

The design of water features based on an engineering approach considers mainly technical factors such as the type of installation, type of display and features components (basin,

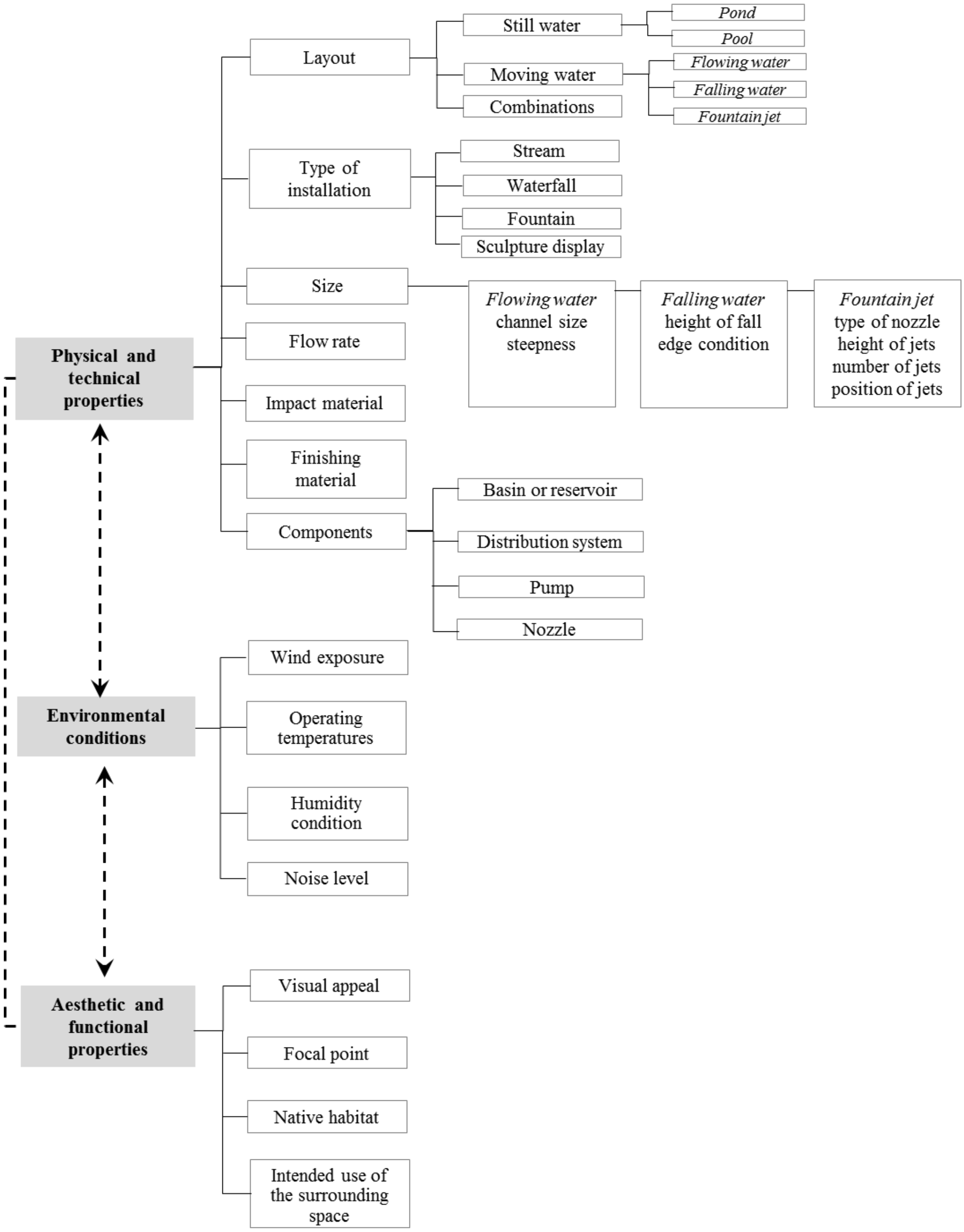


Figure 2.8 Scheme of design factors for water features using an integrated landscape/architectural and engineering approach, derived from literature review.

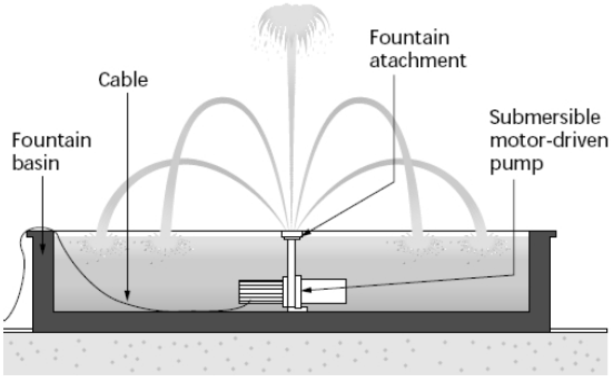
and reservoirs; pumps; plant space and location; distribution system such as nozzles valves, floor drains) as significant components to be taken into account by designers (Figure 2.8). According to the CIBSE Guide G (2004), it is possible to define water features on the basis of different types of display:

- ✓ Natural display where materials are used to simulate natural effects. These displays include waterfalls, cascades, water staircases and similar systems.
- ✓ Statuary display achieved by using water emitting from statues or water rebounding from statues.
- ✓ Water jets display achieved by using columns or jets of water where the water could be level-dependent (the jets are below the water level) as well as level-independent (the jets are positioned above the water level).

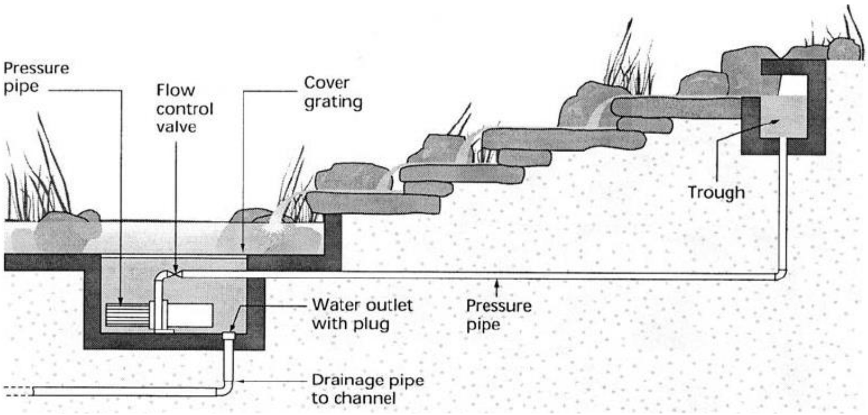
The CIBSE Guide G (2004) describes also installation principles used for small to medium sized fountains and waterfall. In general, a *fountain* is composed of three main elements as shown in Figure 2.10(a): a basin or reservoir filled with water; a submersible or dry pump to re-circulate water and a fountain attachment. In this structure water is sucked through the suction pipe into the pump. The pump discharges the water back into the basin or reservoir via the pressure pipe and nozzle (or nozzles) (CIBSE, 2004). Artificial *streams* simulate effects found in nature (CIBSE, 2004). In a *waterfall* or *cascade* structure, water flows downwards from a source or pond over a water channel to a downstream reservoir or basin, and is then pumped back to the upper pond as shown in Figure 2.10(b). Additionally, the artificial display of water can be designed by varying different heights of falling water and, two types of pumps can be used in order to create different pressures and provide visual effects. Two types of pump installations are available according to CIBSE (2004):

- ✓ Dry pumps that operate outside the water surface, as shown in Figure 2.11(a).
- ✓ Submersible pumps that operate below the surface of the water (Figure 2. 11 (b)).

Furthermore, fountain display characteristics in terms of wind resistance and noise level are defined by CIBSE (2004). For each type of fountain display a recommended noise level is suggested, as shown in Table 2.3. The noise characteristics (Table 2. 3) that should be taken in account by designers are restricted to the noise levels only, showing again a limited consideration given to the acoustic aspects for the design of water features. The desired effect for water features like a fountain can be provided by using different types of nozzles. The CIBSE Guide G (2004) illustrates the most common shapes of nozzles used in fountains that are listed in the manufacturer’s literature. The types of nozzles illustrated in Table 2. 3 correspond to the same components used by Galbrun and Ali (2013) for testing different designs of water features constructed in the laboratory. Additionally, the water features presented in this thesis have been selected from this pool

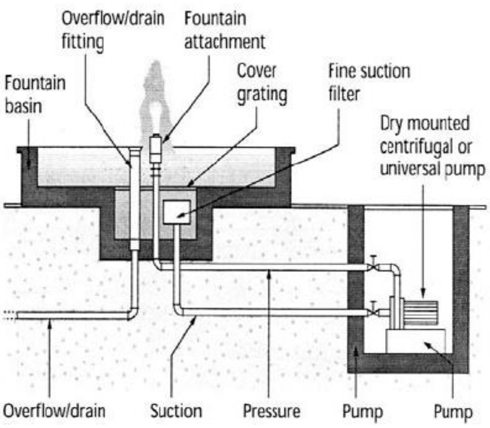


(a) Fountain installation

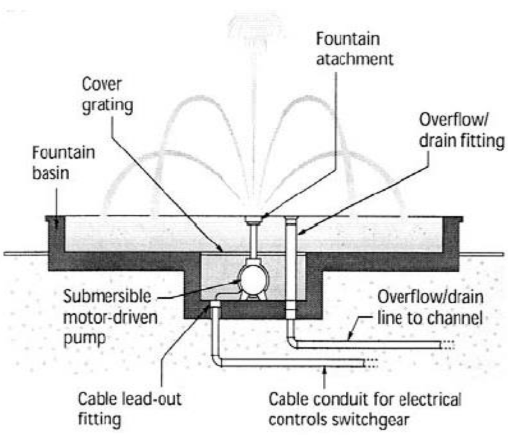


(b) Cascade installation

Figure 2.9 Examples of installations of water features.
(a) Fountain and (b) Cascade installations (CIBSE, 2004).



(a) Dry pump fountain.



(b) Submersible pump fountain.

Figure 2.10 Typical fountain installations (CIBSE, 2004).

Table 2.3 Fountain display characteristics chart (CIBSE, 2004).

Display foam effect jet	Wind resistance	Noise level
Water level-dependent	Low	Low
Water level-independent	High	High
✓ Single jet	Fair	Low
✓ Multi-jet	Fair	Low
✓ Lava jet	Very low	Very low
✓ Aerated waterfall	Very high	High
✓ Smooth-sheet waterfall	Very low	Very low

of data (Galbrun and Ali, 2013) and correspond to:

- ✓ Single jet nozzle: a precision jet nozzle which produces a relatively stable, clear full stream jet (CIBSE, 2004).
- ✓ Foam jet nozzle: produces a white jet through the action of the surrounding water and air being drawn into the nozzle and thrown upwards (CIBSE, 2004).
- ✓ Lava jet nozzle: produces perfectly formed water bells or a dome (CIBSE, 2004).
- ✓ Multi-jet nozzle: comprises a precision set of jets which creates a clear stream of jets rising in one or more water levels (CIBSE, 2004).

Acoustic/soundscape design

Perkins (1973) observed that "waterfalls are not just visual delights, the sound of splashing, gurgling and bubbling is important especially when you cannot hear the traffic." In the design of water features, acoustic criteria did not always appear to have figured out, presumably because of a lack of knowledge of how to predict and plan the effectiveness of acoustic masking in any particular setting, as pointed out by Brown and Rutherford (1994). Contemporary landscape and urban designers are usually looking at water features as elements to be included in the urban/landscape settings with mainly aesthetic considerations constrained by an attachment to the picturesque (Perysinaki, 2010). The design of any particular water structure by using a landscaping/architectural or engineering approach is based on criteria related to physical/technical and aesthetic/functional criteria such as the setting, available space, visual appeal, and the intended use of the surrounding space. Therefore, designers and planners have not been questioning themselves about the acoustical aspects of water features at the very early stage of the design process, relegating the problem to acoustic post – design consulting.

A new approach of the design of water features can be developed using the concept of 'acoustic ecology' defined as the study of sounds in relationship to life and society. "Acoustic design is to regard the soundscape of the world as a huge musical composition in which designers are simultaneously its audience, its performers and its composers" as stated by Schafer (1994). The only principle to guide acoustic designers is always to let nature speak for itself (Schafer, 1994). Water can be organically moulded and shaped in view of creating its most characteristic harmony in the sonic environment: a water concert could become the objective of an exciting collaboration between a sculptor and an acoustic designer (Schafer, 1994). This new concept of designing water features aims at focusing attention of designers on investigating acoustical and non-acoustical features of sounds and finding a relationship with subjective perceptions.

This is called the soundscape approach and is explained in detail in section 2.5.2. Based on this approach, the acoustic use of water generated sounds has been widely recognised as a potential mean for masking annoying urban noise (Figure 2.11) by taking advantage of their distracting effect as "wanted" sounds (Watts *et al.*, 2009), as well as improving soundscape perception due to their inherent positive qualities (Kang, 2007). Several studies applied the soundscape approach for studying how to improve acoustic environments by introducing pleasant sounds such as sounds from water features, and these will be illustrated in detail in section 2.5.7. Although several efforts have been made in recent researches towards investigating the acoustic and perceptual properties of water generated sounds, it is not yet still possible to define a specific guideline for the soundscape design of water features.

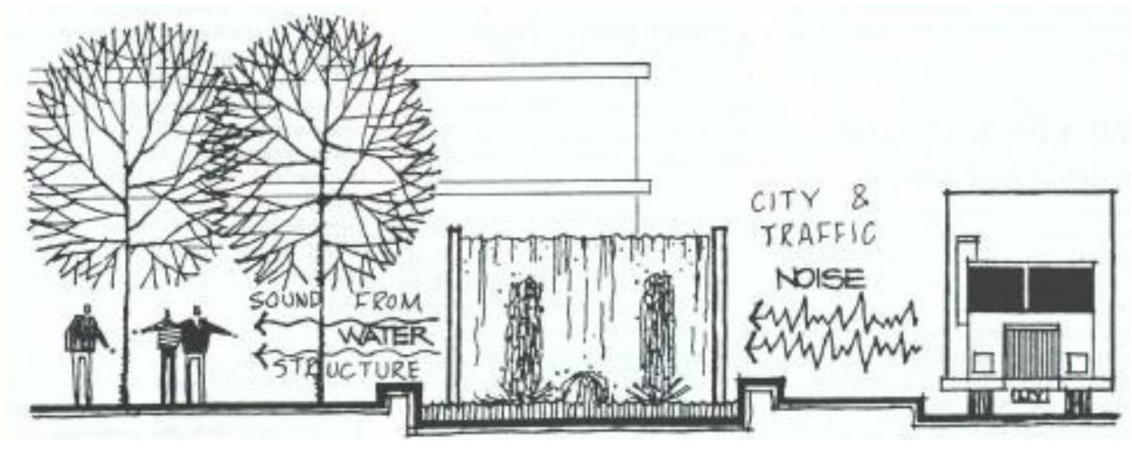


Figure 2.11 The acoustic use of water generated sounds for masking city noise (Brown and Rutherford, 1994).

2.4.5 Discussion

Water represents an important element to survival and has a symbolic meaning of cleansing, purification, refreshment and renewal among different cultures. Throughout history, it has been recognised as a fundamental element for creating a feeling of calmness and playing an important role in architectural design. For that reason, integrating water features into architecture has been considered to suggest and promote a sense of beauty and visual appeal, of tranquillity and contemplation, or vivacity and freshness since ancient times.

Different types of water features can be found in nature, and these can be also classified from a design point of view. In landscape/architectural and engineering approaches, the principles and concepts applied to the design of water features have typically focused on the central visual-aesthetic aspects of the water structures, the settings and available space, the type of installations and features components such as basins, pumps or the water system distribution. Therefore, although non-visual qualities of water have been recognized as important elements, little attention has often been paid to the acoustic aspects of water features at the very early stage of the design process, relegating the problem to acoustic post – design consulting. Few considerations on water generating sounds are reported in the scientific literature (Booth, 1989), and these refer only to sound effects as a product of the visual design and are only based on a merely qualitative description (e.g. a “soft hiss” emitted by a spray). Moreover, some examples of recommended noise levels can be found in the literature (CIBSE, 2004), but these indicate only different levels (e.g. very low, low, high or very high) based on the type of installation, showing again a limited consideration given to the acoustic aspects for the design of water features.

2.5 Soundscape approach: a review of previous works

2.5.1 Background

In the European Union, about 40% of the population is exposed to road traffic noise which is inducing adverse consequences to human well-being (WHO/European Communities, 2012). The Environmental Noise Directive (END) introduced a common approach intended “to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise” (END/European Communities, 2002). The Directive provides a common approach for the assessment and management of environmental noise across Europe including four elements of harmonization of noise indicators such as L_{den} (day-evening-night noise indicator), L_{day} (day-noise indicator), $L_{evening}$ (evening-noise indicator) and L_{night} (night-noise indicator). "In determining noise limit values EU countries must take into account the need to preserve quiet areas in agglomerations, and aim to protect quiet areas against an increase in noise" (END/Europe Communities, 2002). "Quiet area in agglomeration" shall mean an area, delimited by the competent authority, for instance which is not exposed to a value of L_{den} or of another appropriate noise indicator greater than a certain value set by the Member State, from any noise source (END/European Communities, 2002). According to DEFRA (Department of Environment, Food and Rural affairs) (2011), the limits of these indicators range from 40 to 55 dB (DEFRA, 2011). At first sight, the Directive fits firmly within the traditions of noise control, but it is clear that it also contains elements that support the soundscape planning. The new approach suggested by END (2002) refers not only to the quieting of already noisy areas, but also to the protection of quiet areas against increases of environmental noise (Brown *et al.*, 2011). Additionally, the Directive defined a need to undertake strategic maps (for all cities with a population over 250,000 by 2007, and over 100,000 by 2012) as well as action plans on environmental noise aiming at preserving the existing acoustic environments with good sound quality of: these aspects show again a relevance to soundscape planning by identifying locations where there is a potential for soundscape applications (Brown *et al.*, 2011).

2.5.2 Differences between noise control and soundscape approaches

Noise management is the current paradigm for planning, designing and management of acoustic environments, involving a large body of knowledge, practice, law, policing and control activities (Brown and Muhar, 2004). The introduction of the sound quality concept led to noise criteria based on acceptability and listening preference of individuals as well as on minimizing the negative effects of noise (Brown and Muhar, 2004). In this scenario, the complementary approaches of soundscape planning and noise control can be illustrated by three essential differences between them (Brown and Muhar, 2004).

First, the noise control approach in urban areas considers sound as a waste product to be managed like all wastes (Axelsson *et al.*, 2010a) causing human discomfort such as sleep disturbance, interference with communication and annoyance. This approach showed that the human response to "waste" sound's effects is only related to the sound level and the management of sound can be achieved by reducing its level. In contrast, the soundscape approach focuses on sound not just as a waste to be managed (De Coensel *et al.*, 2010), as the acoustic environment is considered as a resource. Rather than concentrating on unwanted sounds that cause human discomfort, the focus now is much more on which sounds people want or prefer.

Second, there is a difference between noise control and soundscape planning in the locus of application. Noise control uses three strategies for action such as control at the source, management of the transmission path between the source and receiver and the protection of the receiver (Brown and Muhar, 2004): it is active in each of these strategies and it aims to protect people who are indoors from noise generated outdoors. In contrast, soundscape planning aims at the planning and management of sound heard in open spaces, although not exclusively so (Brown and Muhar, 2004).

The third difference is related to the acoustic objective to apply in the design process. Noise control in urban areas deals with "sounds of discomfort", sounds that disturb sleep, interfere with communication, distract or annoy people and this aims at minimizing negative effects on people exposure situations (Brown and Muhar, 2004). By contrast, soundscape planning focuses on acoustic environments that are regarded positively, so are preferred or considered as desirable environments by people (Brown and Muhar, 2004). Soundscape management is based on the concept that noise limit values are counterproductive: its acoustic objective is that 'unwanted' sounds must not be heard and natural sounds should dominate in the area of study considered (Axelsson *et al.*, 2010b).

2.5.3 Defining soundscape and its application

A new area of research, called acoustic ecology, was developed by Schafer (1977) and Truax (1978) and defined as "the study of the effects of the acoustic environment on the physical responses or behaviour of those living in it" (Schafer, 1994). The field of study related to acoustic ecology is not ecological in a literal sense, but it is referred to the study of natural sounds and how people perceive an acoustic environment. This new concept of acoustic provided important contributions to the development of soundscape research which identifies a need to allow nature to create its natural sound. Schafer proposed a question to support this theory: "is the soundscape of the world an indeterminate composition over which we have no control, or are we its composers and performers, responsible for giving it form and beauty?" (Schafer, 1994).

The pioneering research in the soundscape approach was carried out by Schafer in the 1960s. Furthermore in the early 1970s, Schafer focused on studying noise pollution and the lack of awareness that humans have of their acoustic surroundings (Pijanowski *et al.*, 2011), so that he defined the notion of soundscape as an “auditory property of landscape” (Raimbault and Dubois, 2005) and “how people consciously perceive their environment” (Kang, 2007). Thereafter, Truax (1978) defined a soundscape as “an environment of sound with emphasis on the way it is perceived and understood by the individual or by a society. It thus depends on the relationship between the individual and any such environment.”

The soundscape concept has been adopted by community noise control as a way to consider noise in cities in a more positive manner and take into account the subjective experience of people (Raimbault and Dubois, 2005). However, soundscape research involves different fields of practice, diverse approaches and diverse disciplines (Brown *et al.*, 2011). It includes acoustic, physical, social, cultural, psychological and architectural aspects related to the product of sound quality. Recent researches showed that decreasing sound levels or eliminating noise is not sufficient to improve the acoustics of urban environment (Kang, 2007). However, it emerged that the sound quality cannot be evaluated only by a simple physical measurement; non-acoustical factors, such as audio-visual interaction, play an important role (De Coensel and Botteldooren, 2006).

Additionally, non-acoustical features can influence the assessment of soundscapes and the visibility of an ‘unwanted’ sound can add negative reactions to the soundscape itself (Raimbault and Dubois, 2005). Based on these considerations, it was suggested that urban planners should compose new urban soundscapes by considering psycho-social factors as well as physical requirements (Raimbault and Dubois, 2005). Furthermore, the centrality of human perception was also highlighted as a relevant aspect for the assessment of soundscape quality (COST Action TD0804, 2013).

Soundscape exists through human perception of the acoustic environment of a place, this refers to “the acoustic environment as perceived by humans” as well as “the total collection of sounds-the physical phenomenon” (Brown *et al.*, 2011). The concept of soundscape can be thought of as an alternative approach to exclusively quantitative approaches in order to overcome the limits of noise annoyance indicators and to handle more general concepts of sound quality (Raimbault and Dubois, 2005) . Furthermore, in soundscape design three different approaches can be identified: a ‘defensive approach’ to protect the environment from acoustic pollution, an ‘offensive approach’ to consolidate the acoustic environment, and a ‘creative approach’ to compose the sonic landscape (Brown and Muhar, 2004).

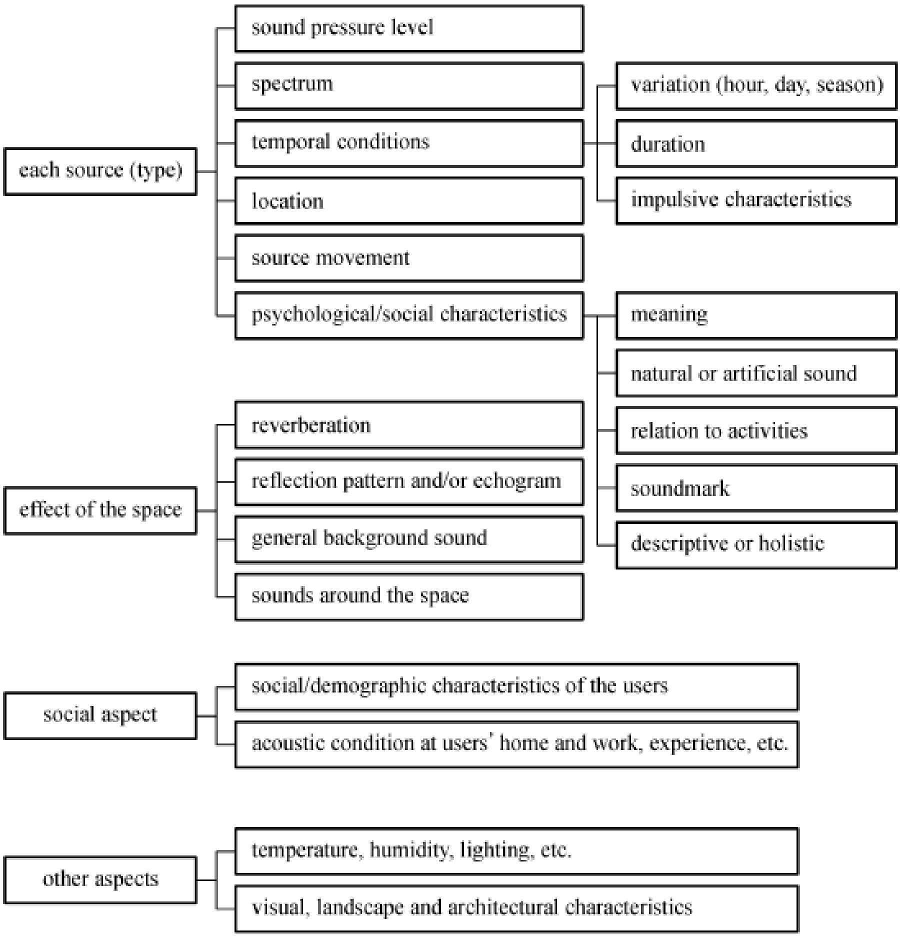


Figure 2.12 System of designable factors for soundscape design in urban open spaces (Kang, 2010).

Although several efforts have been made to understand how to apply the concept of soundscape to landscape and urban planning and design, there is no unique method associated to the assessment of soundscape perception. However, Kang (2010) made a first attempt to identify a system of designable factors which should be considered for the soundscape design in urban open urban spaces, as shown in Figure 2.12. Based on this system, four factors such as the characteristics of each sound, the acoustic effects of the space, the social/demographic aspects of the users and other aspects related to the physical/environmental conditions should be evaluated (Kang, 2010).

2.5.4 Towards standardisation and projects

Great interest has been widely shown in soundscape research with several studies evolving differently around the world, as well as across disciplines, generating diversity of opinions about the definition and aims related to this new research approach (ISO 12913-1, 2014). The International Organisation Technical Committee 43 / Sub-

Committee 1 / Working Group 54 made the first effort to develop a soundscape standard resulting in the ISO 12913-1 published in 2014. This international standard aims "to enable a broad international consensus on the definition of 'soundscape', and provide a foundation for communication across disciplines and professions with an interest in soundscape". According to ISO 12913-1 (2014), a soundscape is defined as an "acoustic environment as perceived or experienced and/or understood by a person or people, in context". Additionally, a conceptual framework related to the soundscape process is provided in this standard, as shown in Figure 2.13. A soundscape originates in sound sources (e.g. road traffic, chirping birds, voices, waters sounds, etc.) and their distribution in space and time. The acoustic environment is defined as "the sound from all sound sources as modified by the environment due to effects of sound propagation, resulting from meteorological conditions, absorption, diffraction, reverberation and reflection." The first stage for detecting and defining the acoustic environment is represented by the auditory perception defined as "the function of a neurological process that starts when auditory stimuli reach the receptor of the ear." This process is influenced by masking, spectral contents, temporal patterns and spatial distribution of the sound sources (e.g. psychoacoustics). "The interpretation of auditory perception refers to unconscious and conscious processing of the auditory signal": this process will be useful to create awareness or understanding of the acoustic environment. "The awareness of the acoustic environment, in context, represents an experience of the acoustic environment." Responses include short-term reaction and emotions, as well as behaviours, whilst outcomes consist of an overall, long-term consequence facilitated by the acoustic environment, such as attitudes, health, well-being and quality of life. All

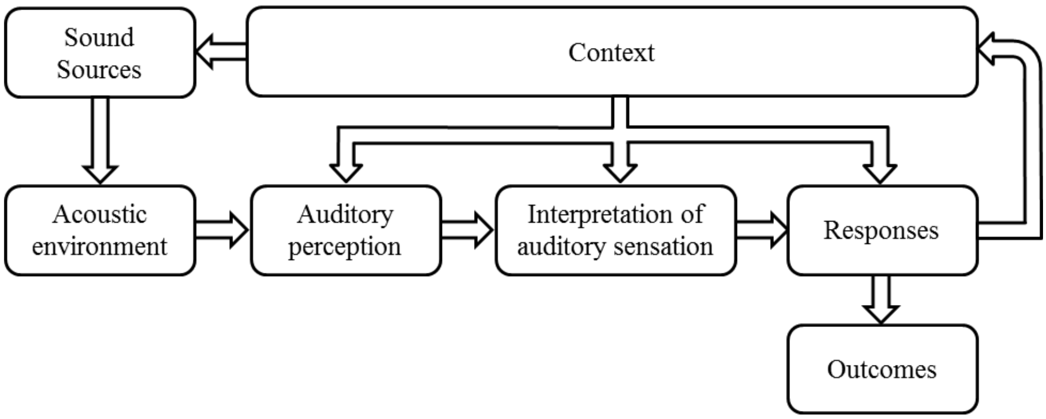


Figure 2.13 Elements in the perceptual construct of soundscape (ISO 12913-1, 2014).

these factors can be influenced by the context which includes the interrelationships between the person, the activity and the place. The impact of the context on a soundscape could be through the auditory perception, the interpretation of auditory sensation and the responses to the acoustic environment.

In addition to the recognised need of standardisation, several activities in the field of soundscape research showed a great interest in different applications:

- EU Directive 2002/49/CE referring to the preservation of good sound quality in existing acoustic environments, as well as the protection of quiet areas (as already illustrated in section 2.3.1);

- US National Park Service working on the management and preservation or restoration of quiet areas in parks, since natural sounds have been recognised in law and policy as a park resource (Miller, 2008);

- EU COST Action on Soundscape (2009-2013) (European Cooperation in Science and Technology Action on Soundscape of European Cities and Landscape) aiming at providing a support for practical guidance in soundscape, consisted of an international network of 52 participants from European countries and 10 participants outside Europe. This included five working groups involved in understanding and exchanging knowledge, collecting and documenting methods and procedures that were being used in soundscape studies, harmonising the current methodology and developing a standard protocol, providing a practical guidance and tools for the design of soundscapes, and finally creating awareness among the general public and policy makers, and providing a training for early-stage researchers. This work resulted in a collection of research publications for all the field evaluated by each working group (COST Action TD0804, 2013).

- Several large research projects have been carried out in the soundscape field: 1) the 'Positive Soundscape Project' (2006-2009), consortium of five universities (Salford, Warwick, Manchester, Manchester Metropolitan and London Arts) in the UK funded by the EPSRC (Engineering and Physical Science Research Council); 2) the 'Soundscape Support to Health' project (2000-2007) funded by the Swedish Foundation for Strategic Environmental Research; 3) 'Sonorus, the Urban Sound Planner' project (2012-2014), a consortium of universities included in the 7th Framework Programme funded by CORDIS (Community Research and Development Information Service) aiming to offer education to future urban sound planners; 4) the EU project 'Hosanna' (Holistic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means) (2009-

2013) coordinated by Chalmers University of Technology, Sweden, and focused on the reduction of road and rail traffic noise in outdoor environment and the use of vegetation on urban and rural surfaces, innovative barriers including recycled materials, and treatments of the ground and the road surface; 5) the 'Quietening Open Spaces. Towards Sustainable Soundscapes for the city of London' is a project that was carried out by the Environmental Protection (UK) and commissioned by the City of London in 2010 in order to research and summarise best practice in protecting and quiet areas for a liveable city (Department of Environmental Services, 2010).

2.5.5 The assessment of soundscape perception

Particular attention has been paid to urban environments in soundscape research up to now. The relationships between the perceived soundscape quality and acoustic, physical and visual properties of environments have been the most important aspects used to evaluate a soundscape. Furthermore, the perceptual assessment of sound preference has been evaluated in previous studies through the use of socio-acoustical surveys, laboratory listening tests, physiological measurements and soundwalks. Soundwalks and laboratory listening tests have been frequently used with the general purpose to encourage people to listen carefully and make judgments about the sonic environment and sounds that they are experiencing (Kang and Zhang, 2010). Listening is one of the psychological functions through which people perceive the world, and the evaluation of sound effects on individuals depends primarily on subjective principles. There are two kinds of sounds relative to different ways of processing in terms of listening (Kang and Zhang, 2010). One is the 'holistic hearing', which processes the soundscape as a whole without semantic processing, and where only background noise is considered as the main factor. The other one is the 'descriptive listening' which aims at identifying sound sources or events. In this context, the field of psychoacoustics has contributed to overcome the difficulties of studying subjective perception of soundscapes and to understand the limitations of acoustic classical parameters, such as the A-weighted sound level, as criterion metrics (Lercher and Schulte-Fortkamp, 2003). Furthermore, the study of soundscape quality with the help of semantic processing has become very important for evaluating subjective perception. The semantic differential technique has proved to be a useful method to identify the most important factors in sound quality evaluation through studying the emotional meaning of words (Kang and Zhang, 2010).

In several studies on the assessment of soundscape perception and sound preferences in urban environments, people showed a similar tendency of preferring natural sounds (Gramann, 1999) (Yang and Kang, 2005a) (Yang and Kang, 2005b) (Jian *et al.*, 2005); and adding 'wanted' sounds was identified as an efficient strategy for improving the soundscape perception. Additionally, it was demonstrated that individual soundscape perception might be influenced by the acoustic environment (sound source identity such as natural, artificial or soundmarks), physical contexts (interaction between visual and auditory aspects, lighting, thermal condition and olfactory aspects), and the psychological contexts (socio-cultural and individual factors such as personal experience and sensitivity to the soundscape components) (Kang, 2007) (Yang and Kang, 2005a) (Figure 2.13). However, Yu and Kang (2008) pointed out that the effects of social/demographic factors such as age, gender, occupation, education and residential status are generally insignificant on sound perception in urban settings. In particular, it was found that social-demographic/cultural factors have no influence in perception of water sounds (Yu and Kang, 2010) (Galbrun and Ali, 2013), perhaps because water plays an important role in urban soundscape and is enjoyed by everybody, regardless of socio-demographic / cultural differences (Yu and Kang, 2010).

<u>The evaluation of perceptual components in soundscape perception</u>

Several efforts have been made in previous research to prove that a soundscape can be characterized by perceptual components. It has been pointed out that the description and evaluation of a soundscape is rather complicated because of the need to study the acoustic environment taking into account how people perceive it. However, it has been suggested that identifying relevant semantic perceptual components is an efficient tool for representing the subjective perception of the soundscape. In Tables 2.4-2.5-2.6, a summary is given for main findings obtained from previous studies involved in the assessment of soundscape perception through a semantic differential analysis (Raimbault *et al.*, 2003) (De Coensel and Botteldooren, 2006) (Guillén and López Barrio, 2007) (Davies *et al.*, 2009) (Jeon *et al.*, 2010) (Kang and Zhang, 2010) (Axelsson *et al.*, 2010) (Jeon *et al.*, 2011) (Cain *et al.*, 2011) (Jeon *et al.*, 2014) (Hong and Jeon, 2015); where, the findings are reported in terms of semantic components, their definitions and semantic attributes associated to them. Previous research mainly focused on evaluating the perception of urban or rural quiet soundscapes by considering the effects of all sounds identified and studying their effect together. Several components were identified in different soundscapes. Firstly, some aspects related to the emotional response were classified in most of the studies as the main factors affecting soundscape perception and were defined as calmness, relaxation, satisfaction, emotional assessment and strength, pleasantness and harmony (visual and acoustic enjoyment of soundscapes). Secondly, aspects related to the sound quality and compositions of the soundscape such as temporal balance, spatial dimension, eventfulness (complexity), clarity, vibrancy (how sound sources change over time), activity (related to the liveliness, the informative nature and variation of sound in time) were identified as important elements for the assessment of a soundscape. Finally, social aspects and components related to people' experiences (familiarity) were recognised as important but less significant factors influencing soundscape perception.

On the other hand, few studies (Jeon *et al.*, 2012) (Radsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013) examined the effect of water sounds on soundscape perception and tried to identify the semantic components related to the waterscapes considered as shown in Table 2.6 (more details on these studies are given in section 2.3.7). Factors related to the acoustic characteristics of water sounds ('freshness' and 'vibrancy') and emotional responses ('calmness' and 'pleasantness') showed a significant effect on the soundscape perception (Jeon *et al.*, 2012). Additionally, it was shown that the effects perception of waterscapes depend mainly on pleasantness and eventfulness as main perceptual dimensions (Radsten-Ekman *et al.*, 2013). Highly pleasant water sounds may increase the overall pleasantness of the acoustic environment (Radsten-Ekman *et al.*, 2013). Furthermore, Hong and Jeon (2013) found that two main factors ('overall quality' and 'spatial impression') are important for soundscape preference when water sounds are used over road traffic noise at 55 dBA, whilst three factors ('pleasantness', 'acoustic comfort' and 'spatial impression') resulted to be significant for perception in the presence of road traffic noise levels at 70 dBA. These results pointed out that the principal components of the soundscape qualities change with different background noise levels (Hong and Jeon, 2013).

Table 2.4 Summary of previous research (2003-2009) related to the assessment of soundscape perception by using a semantic differential method. The findings are given as semantic components, percentages of their explained variance and definitions, the semantic attributes and their description.

Research	Type of study	Component	Explained variance	Definition	Semantic attributes	Description
Raimbault *et al*. (2003)	Perception of the urban sound in two French cities.	1	67%	Assessment and strength	Pleasant/unpleasant; Quiet/loud.	Depends on sound level parameters and subjective perception.
		2	15%	Temporal balance and spatial arrangement	Steady/unsteady; Organised/unorganised.	Related to sound dynamics.
		3	8%	Spatial dimension and clarity	Little attending/very attending; far/nearby; distinct/hubbub.	Associated to background noise in the acoustic space.
De Consoel and Botteldooren (2006)	Assessment of a quiet rural soundscape.	1	52%	Pleasantness	Silent/loud; natural/unnatural; relaxing/rough, exciting/boring; open/enveloping.	High values of factor 1 correspond to a more pleasant soundscape.
		2	16%	Eventfulness	Not sharp-sharp; complex-simple.	Low value indicates more simple (or clear) composition of the soundscape and more high frequency components.
Guillén and López Barrio (2007)	Assessment of soundscape quality in urban environments.	1	42%	Emotional evaluation and Strength	Comfortable/Uncomfortable; Pleasant/Unpleasant; Relaxing/Stressful; Nice/Ugly; Liberating/Oppressive; Allows/Disguises communication; Silent/Noisy; Weak/Strong; Human/Technological; Interesting/ Boring; Safe/Unsafe.	Related to the appreciation of pleasure produced by listening to the soundscape.
		2	14%	Activity	Animated/dull; Informative/non informative; monotonous/varied.	Related to the liveliness, the informative nature and variation of sound in time.
		3	10%	Clarity	Clear/confused.	Related to the clarity with which sound sources can be perceived.
Davies *et al.* (2009)	'Positive soundscape project'-urban spaces.	1	48%	Calmness/Relaxation	Relaxing-stressful; comfortable/uncomfortable; intrusive/not intrusive.	Related to emotional response and strongly to overall pleasantness.
		2	24%	Vibrancy	Cacophony-hubbub; constant-temporal.	Related to sound source and its changes over time.

Table 2.5 Summary of previous research (2010-2011) related to the assessment of soundscape perception by using a semantic differential method. The findings are given as semantic components, percentages of their explained variance and definitions, the semantic attributes and their description.

Research	Type of study	Component	Explained variance	Definition	Semantic attributes	Description
Jeon *et al.* (2010)	Urban soundscape with combined noise/Soundwalk in Seoul	1	79%	Component 1	Comfort/discomfort; quiet/loud; harmonious/disharmonious; soft/rough/; weak/strong; light/heavy; pleasant/unpleasant; warm/cold.	Related to the comfort, loudness, and pitch sensations.
		2	15%	Component 2	Monotonous/varied; unique/common.	Related to the temporal variation.
Kang and Zhang (2010)	Evaluation of soundscape in open urban spaces	1	26%	Satisfaction	Comfort/discomfort; quiet/noisy; pleasant/unpleasant; natural/artificial; like/dislike and gentle/harsh.	Related to relaxation.
		2	12%	Social aspect	Social/unsocial; meaningful/meaningless; calming/agitating and smooth/rough.	Associated with communication.
		3	8%	Fluctuation	Varied/simple; echoed/deadly and far/close.	Associated with spatiality.
		4	7%	Strength	Hard/soft and fast/slow.	Related to dynamics.
Axelsson *et al.* (2010)	Evaluation of urban outdoor soundscapes	1	50%	Pleasantness	Uncomfortable; Comfortable; Appealing; Disagreeable, and Inviting.	This ordered the soundscape excerpts on a pleasant-unpleasant continuum.
		2	18%	Eventfulness	Eventful, Lively, Uneventful, Full of life, and Mobile.	This ordered the soundscape excerpts on an eventful-uneventful continuum.
		3	6%	Familiarity	Commonplace, Common, Familiar, Real, and Rare.	This ordered the soundscape excerpts on a familiar-unfamiliar continuum.
Jeon *et al.* (2011)	Evaluation of urban soundscape/ Soundwalks in Seoul.	1	64%	Component 1	Comfortable/uncomfortable; unpleasant/pleasant; not disturbing/disturbing; quiet/noisy; calm/loud; artificial/natural; distinct/usual; dry/reverberant; not pulsating/pulsating	Related to the comfort, loudness, and temporal variation.
		2	15%	Component 2	Nearby/far; narrow/wide; unsteady/steady	Represents spatial sensations.

Table 2.6 Summary of previous research (2011-2015) related to the assessment of soundscape perception by using a semantic differential method. The findings are given as semantic components, percentages of their explained variance and definitions, the semantic attributes and their description.

Research	Type of study	Component	Explained variance	Definition	Semantic attributes	Description
Cain *et al.* (2011)	The ‘Positive soundscape project’-urban soundscapes	1	52%	Calmness	Comforted, reassured, safe; Intruded upon, disturbed, invaded, unable to hear oneself/not intrusive, not disturbing, able to hear oneself	Combination of ‘‘Calmness and Relaxation’’ ‘‘Comfort and Reassurance’’, and ‘‘Intrusiveness”.
		2	21%	Vibrancy	Fun excited, thrilled, interested, energetic, varied, alert, attentive, sense of life, real	Combination of ‘‘Vibrancy and “Arousal”.
Davies et al (2014)	Using the soundscape dimensions shown by Kang (2007) but in a different city (Manchester, UK)	1	41%	Relaxation/calmness	Like, pleasant, comfort, gentle, quiet, calming, smooth.	-
		2	10%	Dynamics/vibrancy	Varied, meaningful, fast and sharp.	-
		3	7%	Communication	Social and communal.	-
		4	7%	Spatiality	Directional and far.	-
Jeon *et al.* (2014)	Tranquillity in urban religious spaces (Seoul, Korea). – Soundscape perception	1	50%	Pleasantness	Pleasant, calm, chaotic and annoying.	
		2	20%	Eventfulness	Eventful, uneventful, exciting and monotonous.	
	Tranquillity in urban religious spaces (Seoul, Korea). – Perception of the visual environment	1	-	Attractiveness	Appealing, repulsive, harmonious, disharmonious, simple and complex.	
		2	-	Interestingness	Interesting and uninteresting.	
		3	-	Enclosure	Open and enclosed.	
Hong and Jeon (2015)	The influence of functional aspects of urban setting and soundscape perception (Seoul, Korea).	1	35.2%	Harmony	Sound environment, visual environment, sound and visual enjoyment.	Represents the perceived harmony of environments.
		2	22.1%	Eventfulness	Eventful-uneventful; various-monotonous; dynamic-stationary.	It could be interpreted as a variety of sounds.
		3	7.3%	Pleasantness	Pleasant-unpleasant; comfortable-uncomfortable; harmonious-disharmonious.	It represents the pleasantness of sounds.
		4	3.2%	Visual quality	Appealing-repulsive; interesting-uninteresting; harmonious-disharmonious.	Regarding the perception of the visual environment.

Table 2.7 Summary of previous research related to the assessment of waterscapes' perception by using a semantic differential method. The findings are given as semantic components, percentages of their explained variance and definitions, the semantic attributes and their description.

Research	Type of study		Component	Explained variance	Definition	Semantic attributes	Description
Jeon *et al.* (2012)	Assessment of water sounds used over road traffic noise	RTN at 55 dBA	1	51%	Freshness	Warm/cool; weary/refreshing; gloomy/cheerful; unlively/lively; unpleasant/pleasant; closed/open; tired/energetic; monotonous/varied; muddy/clear; dim/distinct; dark/bright.	-
			2	28%	Calmness	Irritated/peaceful; agitated/clam; dissatisfied/satisfied.	-
			3	18%	Vibrancy	Steady/unsteady.	-
		RTN at 75 dBA	1	43%	Freshness	Warm/cool; weary/refreshing; gloomy/cheerful; unlively/lively; unpleasant/pleasant; closed/open; tired/energetic; muddy/clear; dark/bright.	-
			2	29%	Calmness	Irritated/peaceful; agitated/clam; dissatisfied/satisfied.	-
			3	26%	Vibrancy	Steady/unsteady; dim/distinct.	-
Rådsten-Ekman *et al.* (2013)	Assessment of water sounds used	RTN at 57-67 dBA	1	42%	Pleasantness	Pleasant; soothing; annoying; chaotic.	-
			2	39%	Eventfulness	Eventful; uneventful; monotonous; exciting.	-
Hong and Jeon (2013)	Assessment of water sounds used over road traffic noise.	RTN at 55 dBA	1	75.9%	Overall quality	Quiet/noisy; calm/loudness; pleasant/unpleasant; comfortable/uncomfortable; stable/unstable; harmonious/disharmonious; ordered/disordered; various/monotonous; distinct/ordinary; natural/artificial.	Related to the acoustic comfort, preferences, harmony and variety of the soundscape.
			2	12.6%	Spatial impression	Open/closed and wide/narrow.	Related to the spatial perception.
		RTN at 70 dBA	1	70.1%	Pleasantness	Pleasant/unpleasant; comfortable/uncomfortable; stable/unstable; harmonious/disharmonious; ordered/disordered.	Related to the preferences, harmony and variety.
			2	12.3%	Acoustic comfort	Quiet/noisy; calm/loudness; stable/unstable; various/monotonous; distinct/ordinary; natural/artificial.	Related to the acoustic comfort.
			3	7.9%	Spatial impression	Open/closed and wide/narrow.	Related to the spatial perception.

2.5.6 Audio-visual interaction

In this section, audio-visual interaction is examined by reviewing studies involved in the assessment of soundscape/landscape quality with attention to auditory stimuli including natural or artificial sounds. Furthermore, several studies investigated the influence of audio-visual interaction for the assessment of water sounds used over unwanted sounds (Jeon *et al.*, 2010) (Nilsson *et al.*, 2010) (De Coensel *et al.*, 2011) (Jeon *et al.*, 2012) (Hong and Jeon, 2013), and these works are illustrated in detail in section 2.3.7. The interaction between auditory and visual perception can give people a sense of involvement, and lead to a comfortable feeling (Yang and Kang, 2005b). For that reason, visual and auditory aspects play a significant role in subjective perception.

Carles *et al.* (1992) investigated the interaction between aural and visual stimuli by using 32 combinations of sound and images from different landscapes and urban green spaces. Results obtained in terms of preferences showed that the sound and not the visual component dominated the pattern of preference due to the more varied nature of the sounds in comparison with the relatively homogenous quality of the visual scenes shown. Natural sounds were much more preferred to artificial "park noise", and sounds from birds and water moving were the most preferred.

Seven years later, Carles *et al.* (1999) evaluated the influence of audio-visual interactions on the perception of natural and semi-natural landscapes as well as urban green spaces by using 36 combinations of sounds and images in a laboratory setting. Results showed that natural sounds (especially the sound of water) are mostly rated positively, and increase appreciation of natural and artificial settings. Additionally, the congruence or coherence between sound and image influences preferences. According to these results, the authors suggested the need to identify places or settings where the conservation of the sound environment is essential, such as urban green spaces, natural spaces and cultural landscapes.

In a study about the effect of the visual degree of urbanization on auditory judgments, Viollon *et al.* (2002) evaluated the interaction between eight urban sound environments and five visual settings. Results indicated that visual influence on sound perception varied with the visual scenes and the type of sounds concerned. Some types of sound environments were judged significantly more negatively when they were associated with more urban visual scenes (bird songs and all traffic noise), but others (i.e. sound environments involving human activity such as speech) remained unaffected by cooccurring visual stimuli, completely independent of the degree of urbanization of these visual stimuli. According to these results, the authors suggested that the influence of visual properties does not depend on the auditory degree of stress/ unpleasantness: both very stressful sound environments (such as highway traffic noise) and very relaxing sounds (such as bird song) were significantly influenced by the visual degree of urbanization. Rather, visual influence depended on the type of sounds involved. The authors also pointed out that relaxation with human sounds can be more difficult than with natural sounds because the listener can experience a higher degree of implication towards the sound environment and the auditory information: the sound therefore becomes the main focus of attention, and the visual setting does not have a greater influence.

In landscape research, Nasar and Lin (2003) evaluated human responses to different types of water features by using visual tests. Five types of water features that can be used in urban squares were included in this work: still water, flowing water, falling water (waterfalls), jets and a combination of moving water features. Water features' perception was evaluated in terms of three components ('preference', 'calming' and 'exciting') by using bi-polar adjectives. Results for 'preference' showed that subjects gave jets and combinations of moving water features the most favourable rating, followed by still water, falling water and flowing water. For the component 'calming', still water was rated as the most calming feature, followed by the combination and jets, with falling and flowing water receiving unfavourable scores. For the component 'exciting', each moving water represented large improvements over still water. In particular, jets and falling water showed moderate improvements over the combination or flowing water.

In the work by Pheasant *et al.* (2008), the interaction between acoustical and visual factors was examined in the context of tranquil spaces located in urban and rural environments. Results suggested that the A–weighted maximum sound pressure level, L_{Amax}, and the percentage of natural features at any given location were the key factors most closely associated with how tranquil an environment was perceived to be. It was shown that high levels of tranquillity can be achieved with a high percentage of natural features (close to 100%), and man-made noise sources should be characterized by a $L_{Amax} \leq 55$ dB or $L_{Aeq} \leq 42$ dB. Additionally, it was demonstrated that an increase of the perceived loudness of biological noise (sounds made by living organisms excluding human beings, e.g., farm animals, bird songs, humming bees) led to higher ratings of tranquillity, whilst an increase of the perceived loudness of human and mechanical noise were associated to lower ratings of tranquillity.

Liu *et al.* (2014) examined the audio-visual interaction between different types of sounds and visual elements (sky, buildings, vegetation, water, pavement and furniture) of the landscape in five city parks in China through soundwalks. Results showed that the perceived loudness of human sounds (speech, children shouting, footsteps) were negatively associated with the factor 'sky', and positively associated with factor 'buildings'. A positive relationship was also found between the perceived loudness of mechanical sounds (sport equipment, road cleaning, aeroplanes, music) and the factors 'building' and 'vegetation', while the perceived loudness of geophysical sounds (water sounds, leaves rustling and wind) was correlated with the factor 'sky'. Furthermore, no correlation was found between the perceived loudness of road traffic noise as well as biological sounds (sounds from birds, dogs and insects) with any landscape elements. Overall, results showed that the percentage of buildings, vegetation and sky in the panoramic views are effective landscape elements influencing soundscape perception. Finally, it was also pointed out that that the physical composition of the visual landscape in favour of natural sounds should be considered with priority in urban landscape management.

Ren and Kang (2015) evaluated the effects of visual landscape factors (landscape objects such as trees, islands, viaducts and buildings and the distance to the water edge) of an ecological waterscape on acoustic comfort by using audio-visual tests. Results showed that the acoustic evaluations score relating to people's participation (i.e. chatting, road traffic noise, metallic sound from sport equipment) under the effect of artificial landscape objects, are higher than those under the effect of natural landscape objects. With regard to the effect of distance from the water edge, the acoustic evaluation scores of human activity sounds increased when the distance of the waterscapes' view was smaller, while the evaluation scores of acoustic comfort in the case of flowing water sounds reached high values ("comfortable" levels) for both the distant and the closer views. This pointed out that water flowing sounds is not affected by the distance of the view of waterscapes. Furthermore, the acoustic comfort of road traffic noise characterised by low sound levels (30-35 dBA) was poorly rated when decreasing the distance of the view of waterscapes, while no differences in scores were found for the acoustic comfort of road traffic noise associated to high sound levels (65-70 dBA) with both distant and closer views of the waterscape. This result suggested that the context of the visual landscape plays a less significant role in the assessment of the acoustic comfort in settings characterised by high levels of road traffic noise. Finally, it was pointed out that the visual context plays a considerable role in the acoustic comfort of waterscapes: landscape objects can significantly influence the evaluation of the acoustic comfort of sounds related to human activity (chatting, road traffic noise, public radio and sport equipment), while the distance of the view of waterscapes can have a strong impact for assessing the acoustic comfort of natural sounds (bird songs and water flowing sounds).

2.5.7 The assessment of soundscapes by using water sounds

This section gives a review of studies that examined the process of water generating sounds, the evaluation of the quality of water sounds, and finally the use of water sounds as a mean to mask or distract attention away from the ‘unwanted’ sounds, as well as to improve the perception of soundscape.

<u>Water generated sounds</u>

Water makes sounds by falling and impacting on water or on rigid surfaces, thus the sound emitted originates from a physical phenomenon related to the formation of vibrating bubbles in the liquid. The earliest reference to this phenomenon is represented by the book “The World of Sound” of Bragg (1921), where the author provided some consideration on what is sound, and tried to define the physical process of sounds in different contexts, such as sounds in music or the sound of the sea. The author suggested that the sounds emitted by running water originate from cavities created by the impact of liquid drops on the water surface.

The sound of air bubble formed at a nozzle was first investigated by Minneart (1931), who showed that the sound emitted is associated to the volume pulsations of air bubbles. The frequency of the volume pulsation was calculated by as the resonant frequency *f* of a bubble in an infinite volume of water in relation to the bubble’s radius:

$$f = \frac{3}{r} \tag{2.14}$$

where *f* is the resonant frequency (Hz) and *r* is the bubble’s radius (m).

Leighton and Walton (1987) examined underwater sounds through field measurements. Based on Minneart’s formula (2.1), the authors calculated the number of bubbles and radius for sounds originated from four brooks. Results showed that water flowing smoothly over a large stone has a narrow distribution in bubble sound frequency (0-10 kHz) and bubble radius (0.3-0.6 mm). In the case of a rock pool fed by a single falling stream, a narrow spread in bubble frequency (3-12 kHz) and radius (0.3-1 mm) was observed, whilst sounds emitted from a waterfall showed a large spread in frequency (3-24 kHz) and bubble radius (0.15-1 mm).

Additionally, Leighton (1994) investigated the physical phenomenon of underwater sounds, and gave a detailed description of this in the book “The acoustic bubble”. In the case of water falling onto a water surface, the impact sound is of low level and is generated by the bubbles in the water. There is a brief period before the initial contact between water onto water when the contact regions move causing small shock waves with a supersonic speed. The dominant sound is generated by the vibrating bubbles which are formed when air is trapped in the water caused by the water surface, or when air is injected by a nozzle or in cavitation (e.g. ship propeller). Smaller bubbles generated by breaking up large bubbles cause individual sound sources. The vibrating bubbles emit a tonal sound which decays exponentially as energy is dissipated. According to Minneart’s formula (2.14), it is possible to find a relationship between the resonant frequency of bubbles and their radius. Based on this, the author pointed out that the critical size of a bubble for perception is from 1.5 to 150 mm corresponding to the audible range 20-20,000 Hz. As bubbles rise from below the surface, the pressure decreases and frequency rises. The submerged oscillating bubble will thus create a sound, which propagates to the surface of the liquid where it is transmitted to air.

Evaluation of water sounds’ quality

Minorikawa *et al.* (2004) examined the relationship between water flow parameters and acoustical characteristics of water sounds generated from a small stream passing through an opened channel with different steps and obstacles. This work aimed at evaluating sound quality of water sounds from water structures constructed in a laboratory by using psychoacoustic metrics. Results showed that the amount of air bubbles (in other words, the flow’s energy loss due to the jumping water) had an influence on water sounds’ quality. When the energy loss by the jumping water was small, there were few air bubbles produced by the jumping water, and consequently the sound became small. In contrast, a large energy loss increased the sound by increasing the air bubbles. Additionally, a relationship between the degree of comfort obtained in terms of sound perception and psychoacoustic parameters was found: high values of sharpness and fluctuation strength were associated to sounds perceived as uncomfortable.

In a work on sound quality evaluation, Fastl (2005) investigated the perceived loudness of different water structures related to water flow rates. Three different waterfall structures were considered: a waterfall with four straight steps, with four steps with basins and with a gentle grade. Results showed that loudness increases when increasing the amount of water. It was also noted that increasing the amount of water leads to a linear increase of loudness (N) up to a certain level for the waterfall with four straight steps, whilst above that point the loudness tended to be constant. In the case of the waterfall with four steps with a basin, the relation between the amount of water and loudness was fairly linear. Conversely, the influence of the amount of water on the resulting loudness was relatively small for the waterfall with a gentle grade slope.

Among various sounds in the environments, natural sounds (e.g. water sounds and bird songs) have proven to be highly preferred by humans, but the reasons for these preferences have not been thoroughly researched. In this context, Yang and Kang (2013) explored the differences between natural and urban environmental sounds from the viewpoint of objective measures, especially psychoacoustical parameters. Acoustic stimuli included 101 sounds among natural sounds (water sounds from stream, small river, medium river, wave on shingle, wave on sand, wave into cove, wind sounds and bird songs), whilst urban sounds included sounds from fountain, street music, traffic, human voice, church bell and many more. Results showed that three key indices are important to identify differences among different types of sound types, and could be used for sound identification: these are fluctuation strength, loudness and sharpness. Water sounds have low fluctuation strength and a wide range of loudness; wind sounds have low fluctuation strength, a wide range of loudness and low sharpness; bird songs have high fluctuation strength, high sharpness and low loudness; and urban sounds have high loudness. In terms of differences between natural and urban sounds, urban sounds tend to have high fluctuation strength and loudness, while natural sounds have either low fluctuation strength and varied loudness and sharpness, or high fluctuation strength and sharpness and low loudness.

Introducing water sounds as a mean for improving the soundscape quality

The earliest reference to the acoustic use of water sounds in urban environments is the work of Brown and Rutherford (1994), where the authors pointed out a need to apply acoustic criteria as important elements for the design process of water features. Based on the acoustic characteristics (the percentile levels L_{10}, L_{50} and L_{90}) of two city noise settings (roadside and mall settings), different water structures (waterfalls, fountain jets and cascades) were examined and three different acoustic zones were identified with different levels of masking around the structures (‘zone of detection’, ‘zone of influence’ and ‘zone of exclusion’). This work is described in more details in Chapter 7 (section 7.2), due to its relevance in relation to the study of sound maps for water features used over road traffic noise.

Boubezari and Coelho (2004) indicated a need to develop qualitative sound maps in view of connecting soundscape composition to people’s perception and reaction to noise. Contrary to conventional measurements based on the overall values of L_{Aeq}, the authors developed a new methodology which allows understanding the space distribution of a soundscape. Sixty samples of 30 s were recorded in areas of Rossio Square in Lisbon (Portugal) where people circulated at 10 m intervals approximately. By listening and paying attention to one type of sound beforehand (traffic noise, fountain sounds and ambient music), a masking pink noise was gradually introduced until the limit of audibility for the selected sounds was reached. The resulting pink noise levels corresponded to the measured of the designated sound. The measured values allowed drawing the curves of audibility for each value of masking noise in interval of 3 dBA by starting from a L_{mask} value (a zero value indicated that the noise was naturally inaudible in situ without added pink noise). Results indicated that water sound was not audible in the lateral points close to the sidewalks of the fountain where the traffic noise was dominant. Furthermore, the authors developed a sound map that illustrates the soundscape composition that could be potentially heard by some walkers around the Rossio Square. This was suggested as a mean to identify the critical points on the plan where ‘unwanted’ or dominant sound sources are active.

Yang and Kang (2005b) examined the soundscape perception and sound preferences in urban settings (Sheffield, UK) by using field surveys. For soundscape design, introducing soundmarks may have dramatic effects, and according to the type of sounds, soundmarks can be classified as ‘passive’ and ‘active’. A typical passive soundmark, water, in the form of fountains, springs or cascades, is often used as a landscape element in open public spaces. In this research, the sound of water was classified as ‘favourite’ by 79.3% of the interviewees, and results showed that the introduction of water elements had dramatically improved the soundscape quality in the urban squares studied. However, the authors suggested that special attention must be paid to the flow rate: keeping it at a constant sound level may cause people to lose interest and consequently the effects on their psychological adaptation will diminish with time.

Watts *et al.* (2009) measured and assessed water generated sounds with the aims of evaluating their masking effects and impact on the assessment of tranquillity in different background noise situations. Different water sounds were generated in the laboratory under controlled conditions (water falling onto water, water falling onto gravel, bricks and small boulders, water falling over a cavity). Water splashing onto hard surfaces tended to produce high frequency components, whilst low frequency components were associated with large flows of water dropping onto water (Watts *et al.*, 2009). Additionally, a comparison in terms of octave band spectra between water sounds and typical traffic noise in an urban setting showed that water sounds are effective as a masker at mid-frequencies but not at low frequencies. Furthermore, audio-visual tests were performed to evaluate the perception of water sounds in the context of tranquillity (levels were set at approximately 40 and 50 dBA representing a realistic range in suburban areas). Results showed that the higher frequency variable water sounds (generated from water falling onto small boulders) were mostly high rated in terms of preference, whilst sounds from water falling into cavities (with lower frequency contents) were poorly rated. This suggested that water sounds could not be a good masker for road traffic noise, but could be an efficient mean to divert attention of individual from the unwanted sounds by providing a pleasant sound. Finally, it was shown that preference scores increase when visual stimuli are included in the tests, and natural looking features tend to increase preference scores, while manmade looking features decrease them.

Jeon *et al.* (2010) examined the perceptual assessment of soundscape quality through soundwalking; several urban soundscapes in Seoul and Bundang (Korea) were evaluated by using a subjective approach (semantic differential test) for assessing the annoyance of combined sources (water sounds + construction noise), and a quantitative approach (5-point verbal scale and 11-point numerical scale) for evaluating the annoyance responses to road traffic noise and construction noise. The qualitative analysis showed that the two main components affecting soundscape perception were the acoustic comfort and loudness, and these could be represented by such adjectives as “comfort”, “quiet” and “weak”. Additionally, the annoyance ratings for construction noise in combination with road traffic noise were related to the type of construction noise (stationary and non-stationary) and different road traffic noise levels (55 and 75 dBA) (road traffic noise with small fluctuations). A laboratory experiment was also carried out to evaluate the use of water sounds for enhancing soundscape perception. Water sounds such as “stream” and “waves of lake” were preferred and rated as the best sound to use for improving perception in the presence of road traffic noise. Moreover, results suggested that the urban soundscape can be enhanced when the level of water sounds is similar to or not less than 3 dB below the level of urban noise.

Nilsson *et al.* (2010) investigated the masking effects of fountain sounds used over road traffic noise. Listening experiments were carried out using binaural recordings from a city park in Stockholm exposed to road traffic noise and sound from a large fountain located in the centre of the park. Results showed that fountain sounds can reduce the loudness of road traffic noise in a region close to the fountain: these can have a positive effect for improving soundscape quality in a region 20-30 m around the water structure where water sounds were loud or louder than the road traffic noise. In order to quantify the masking effects, listening tests were carried for assessing loudness of combined sounds (target sound combined with 65 dB masker sound) and the level differences between the target sound heard alone and an equally loud target sound heard together with masker sound was calculated. For road traffic loudness, the level differences was moderate (from -6 to +1 dB), whilst differences in loudness for water sounds were larger (from -15 to 0 dB). The asymmetry in perceived masking between road traffic noise and water sounds could be explained by the larger proportion of low frequency in traffic noise compared to fountain sound. The authors pointed out that it is well known that low-frequency sounds are harder to mask than high frequency sounds due to the energetic masking [a masker sound makes a target sound inaudible (complete masking) or less loud (partial masking) by decreasing the signal-to-noise ratio in the frequency regions surrounding the target sound at the basilar membrane]. For that reason, the positive effect for improving soundscape perception around the fountain could be explained by informational masking (perceptual masking), meaning that designing wanted sounds represents an efficient strategy in view of distracting people from unwanted sounds and attracting their attention.

An evaluation of different water sounds was carried out by You *et al.* (2010) in view of improving urban soundscapes in the presence of road traffic noise with small fluctuations. Analysis of temporal characteristic of water sounds pointed out that sounds from streams, falling water, and waterfalls demonstrated continuous sound pressure levels, whilst water sounds from fountains had different temporal characteristics, with sound pressure levels varying with the operation cycle of the fountain. Additionally, sound pressure levels of the water sounds tested ranged between 72 to 82 dB: fountains showed the highest sound pressure levels, whilst the stream exhibited the lowest. Results obtained from the analysis of spectral characteristics showed that road traffic noise have strong energy at low frequencies (from 63 to 250 Hz), and water sounds from a stream and falling water have slightly more energy at low frequencies rather than waterfalls and fountains. At mid-frequencies, all water sounds had similar spectral characteristics. Auditory experiments, based on listening to water sounds and road traffic noise fixed at 55 or 75 dBA (corresponding to the noise exposure of most urban spaces), showed that water sounds with an S/N ratio of -3 dB were preferred. Furthermore, the authors pointed out that sounds from streams and falling water (characterised by higher energy at low frequencies) tend to be very effective for masking road traffic noise.

In a study about the effects of natural sounds on the perception of road traffic noise, De Coensel *et al.* (2011) examined how water sounds can reduce the loudness of road traffic noise due to informational masking effects such as target-masker confusion. Listening tested were carried out on loudness, pleasantness and eventfulness for combinations of road traffic noise with fountain sounds and bird sounds at different sound levels (sound pressure levels of fountain sounds and bird sounds ranged from 49.1 to 73.4 dBA). For each road traffic noise (RTN) level (62.6 dBA for a major road; 65.8 dBA for a freeway and 59.6 dBA for a minor road), two fountain sounds and two bird sounds were selected to be combined with road traffic noise based on the signal-to-noise ratio (SNR): one sound with a sound level 10-15 dBA lower than RTN, and one with a sound level 0-4.5 dBA lower (as suggested by Nilsson *et al.* (2010)). Results showed that adding fountain sounds to soundscapes can reduce the loudness of road traffic noise only if the latter have low temporal variability (e.g. traffic from freeway or major road), confirming also findings obtained by Nilsson *et al.* (2010). Similarly, adding bird sounds had the same effect only for the freeway noise (surprisingly bird sounds had a higher S/N ratio than fountain sounds). The authors gave an explanation to these findings supposing that the auditory attention is drawn to that sound of the mixture which has the highest temporal variability in sound level. Furthermore, results from semantic differential analysis showed that adding fountain sounds only improved soundscape pleasantness significantly for the major road traffic noise situation but not for the freeway noise or the minor road traffic noise. Conversely, bird sounds enhanced soundscape pleasantness and eventfulness of soundscape in all acoustic settings considered. These results suggested that soundscape quality is heavily influenced by the meaning associated to the different sounds that are heard, so that acoustic designers should address their attention not only to the loudness of unwanted sounds. It is however worth noting that only one type of water sound was used in the study (i.e. different findings might be obtained when using different water sounds).

Jeon *et al.* (2012) evaluated the acoustical characteristics of water sounds for improving the soundscape in urban open spaces. A total of 14 experimental sounds were constructed combining different water sounds with road traffic noise fixed at 55 and 75 dBA (representing the typical range of levels of noise exposure in most urban spaces). Water sounds were collected from various water features by recordings in open public spaces in Korea and the United of Kingdom, and these included water sounds from fountains (F), streams (S), waterfalls (W) and falling waters (FW). Water sound levels were maintained with a 3 dB lower A-weighted SPL than that of the road traffic noise, for which the levels was fixed at either 55 or 75 dBA, as suggested by Jeon *et al.* (2010). The analysis of the acoustical characteristics of stimuli showed that all water sounds had similar spectral characteristics at mid-frequencies, whilst road traffic noise showed much lower SPLs than any water sound at high frequencies. The road traffic noise (RTN) showed relatively more energy at low frequencies from 63 to 125 Hz. Among the water sounds, the falling waters (FW) and streams (S), showed slightly more energy than the other water sounds at low frequencies. The analysis of psychoacoustic characteristic of stimuli showed that road traffic noise had low sharpness in comparison to psychoacoustic metrics of water sounds when low frequencies were dominant. However, roughness and fluctuation strength for traffic noise were smaller than those of water sounds. Among water sounds, fountain sounds showed the greatest sharpness, whereas stream sounds had the smallest one. In terms of roughness, water sounds from streams had the smallest value whereas waterfall sounds showed the smallest value of fluctuation strength. Results obtained from listening experiments used for assessing the preference of water sounds showed that, all water sounds combined with traffic noise have a positive judgment compared to road traffic noise alone. Additionally, comparisons of preferences from audio-only and audio-visual sessions revealed that visual images have a significant effect on the perception of urban noise when water sounds are introduced as a sound masker: preference scores increased in most cases as visual images were added simultaneously. Results from the semantic differential tests showed that three main factors (‘freshness’, ‘calmness’ and ‘vibrancy’) are important for the assessment of water sounds used over road traffic noise fixed at 55 or 75 dBA (more detailed information can be found in section 2.5.5). Furthermore, the analysis of correlations between psychoacoustic metrics and subjective results from preferences showed that sharpness was significantly correlated with both preference scores and semantic factor scores under both audio-only and audio-visual conditions. Furthermore, results suggested that greater sharpness is effective in improving ‘freshness’ (positive correlation), but not helpful in enhancing ‘calmness’ (negative correlation). This finding revealed that sharpness could be a dominant factor affecting the soundscape perception of urban environments.

Galbrun and Ali (2013) examined the physical and perceptual properties of water sounds generated by small to medium sized water features used over road traffic noise in the context of peacefulness and relaxation. This work is described in great details below, due to its relevance for the research project presented in this thesis. Different water structures (waterfalls, fountain jets, a cascade and a stream) were constructed in the laboratory (with the exception of the stream tested in the field). The acoustic impact of flow rate, waterfalls' edge design and width, height of falling water and impact materials were analysed. Road traffic noise consisted of dense road traffic with low temporal variability and was recorded in the vicinity of a busy motorway (200 m between the road and receiver). Results in terms of sound spectra suggested that it is difficult to generate low frequency sounds from water features when compared with road traffic noise, and this confirmed previous findings by Watts *et al.* (2009) and You *et al.* (2010). Additional analysis showed a logarithmic increase of the equivalent sound pressure level, L_{Aeq}, with water flow for all types of water features tested, and this logarithmic trend was also confirmed for loudness. Furthermore, results showed that waterfalls can generate low frequencies by increasing the flow rate (up to ≈ +10 dB) (Figure 2.14(a)). In contrast, low frequency sounds cannot be easily produced by increasing the flow rate in features such as fountains, cascades, and jets, as the bubbles generated are too small (Figure 2.14(b)). The analysis of the flow rate's effects on psychoacoustical parameters showed that sharpness exhibited no clear trends for waterfalls, whilst for cascade, fountains and jets there was a small linear increase in sharpness with flow rate. Conversely, roughness decreased logarithmically with flow rate for all the water features tested. From the analysis of different waterfalls' edge design, the authors pointed out that the most effective design for producing low frequencies is the plain edge design, whilst the small holes' edge does not produce low frequencies and shows a spectrum's shape comparable to fountains, as shown in Figure 2.15. The results obtained for different heights of falling water indicated that an increase in the height of falling water increases L_{Aeq} levels noticeably (+5-10 dB). Additionally, it was found that water tends to be the impact material producing higher sound pressure levels at mid frequencies (+5–10 dB in the range of 250 Hz–2 kHz compared to levels from hard materials) (Figure 2.16), whilst the use of hard materials increases the high frequency content and sharpness of the sound and decreases its overall sound pressure level. The perceptual assessment of water sounds for

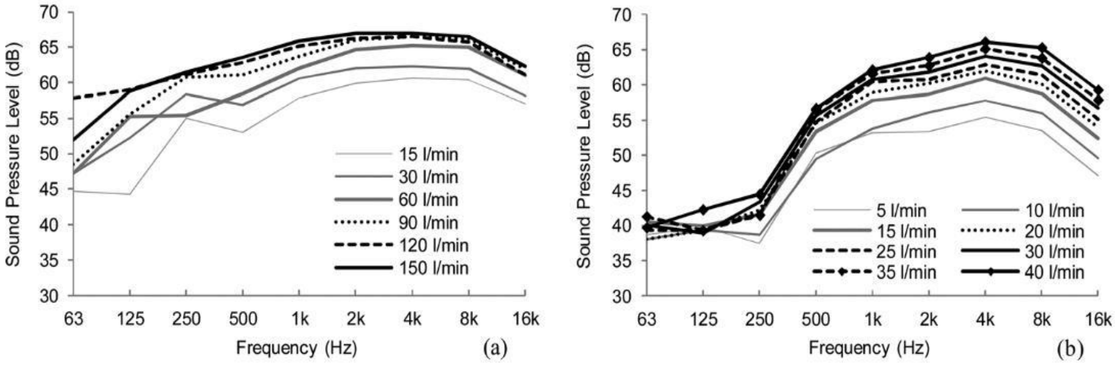


Figure 2.14 Spectra obtained for different flow rates. (a) Plain edge waterfall (1 m width and 1 m height of falling water) and (b) Fountain 37 upward jet with 0.5 m extension (Galbrun and Ali, 2013).

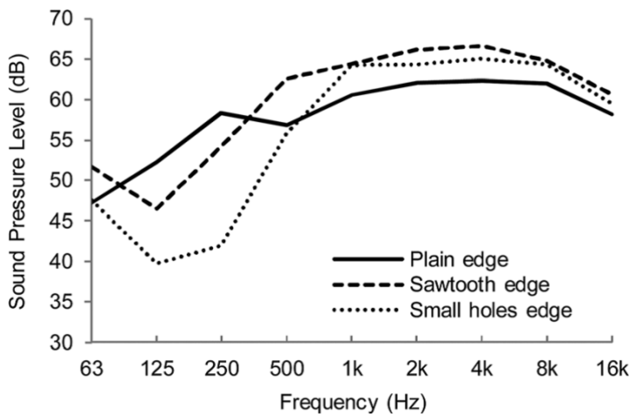


Figure 2.15 Impact of waterfall's edge design on sound spectra (waterfall of 1 m width and 1 m height, with a flow rate of 30 l/m) (Galbrun and Ali, 2013).

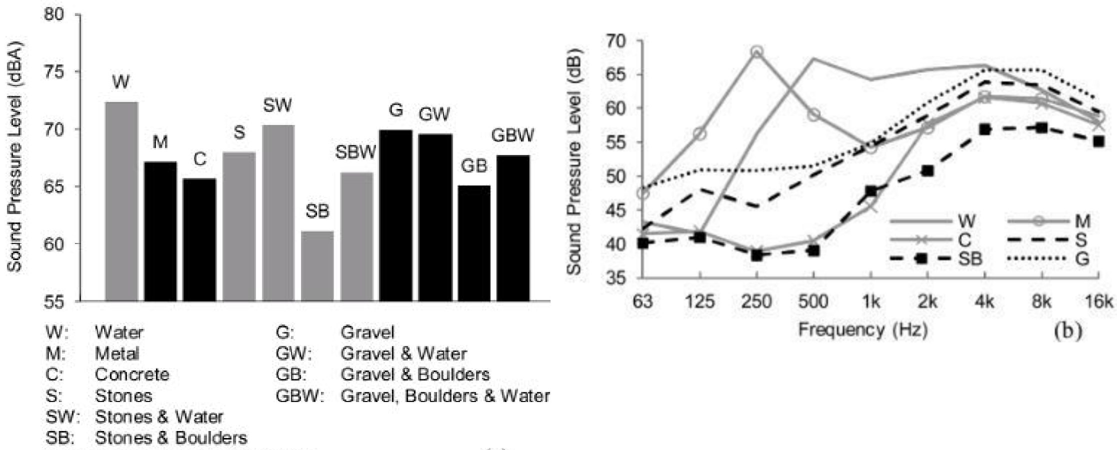


Figure 2.16 The effect of impact materials on sound pressure level for a sawtooth edge waterfall of 1 m width and 0.5 m height of falling water, operating at a flow rate of 30 l/min. (a) L_{Aeq}. (b) Spectra. (Galbrun and Ali, 2013).

road traffic noise masking was also examined in order to identify the preferred sound pressure level of water sounds over road traffic noise and the preferred water sounds in the presence of road traffic noise by using listening tests. Twelve water sounds were obtained from a variety of waterfalls, cascades and fountains and then played (sounds normalised at 55 dBA) over the road traffic noise. Results in terms of preferred sound pressure levels showed that water sounds should be similar or not less than 3 dB below the road traffic noise level, validating the findings of Jeon *et al.* (2010) and You *et al.* (2010). Additionally, it was found that stream sounds tend to be preferred to fountain sounds, which are in turn preferred to waterfall sounds. Further results indicated also that water tends to be the preferred impact material. The analysis made on groups of water sounds by using psychoacoustical and acoustical metrics showed that the preferred water sounds have a larger temporal variation in level (L_{A10}-L_{A90}), a larger low frequency content (L_{Ceq}-L_{Aeq}) and lower sharpness, although no acoustical or psychoacoustical parameters correlated well with the individual sound preferences. This result confirmed the findings obtained by Jeon *et al.* (2012) according to which water sounds defined by the word freshness had a higher sharpness, whilst water sounds defined by the word calmness had a lower sharpness. However, the preference of low sharpness contrasted with the findings by Watts *et al.* (2009) which showed that water sounds with higher sharpness were more highly rated in terms of tranquillity. The authors suggested that this could be explained by the fact that a single type of downwards stream with varying impact materials was tested in Watts *et al.* (2009) compared to those examined in their work (a variety of upward and downward flows). The authors also stated that this might be due to the fact that a downward stream with lower sharpness tends to be associated with man-made sounds such as water falling into a drain or container, and these tend not to be liked.

In a study on the audio-visual interaction of sounds and streetscapes on soundscape perception, Hong and Jeon (2013) carried out some laboratory experiments by presenting acoustic stimuli of natural sounds (bird songs and water sounds) combined with road traffic noise (road traffic noise set at either 55 or 70 dBA, and signal-to-noise ratio set at -3 dBA between the road traffic noise and natural sounds) and visual stimuli representing a street scene with or without green elements. Results showed that an increase in greenery from trees or bushes can improve streetscapes, but water features as visual components may not significantly improve the perceived view. Among natural sounds, it was found that bird sounds are more effective for enhancing soundscape quality in the presence of road traffic noise than are water sounds. Furthermore, results of preferences of water sounds showed that stream sounds tend to be preferred over sounds from falling water, and falling water sounds tend to decrease the overall quality of the environment in presence of noisy background noise levels (Figure 2.28) (road traffic noise levels higher than 70 dBA). Additional analysis showed that the perceptual dimension of streetscapes differ according to the background noise level of road traffic noise (details can be found in section 2.5.5). In particular, the contribution of the acoustic comfort to the overall impression was more significant than visual factors when a high level of road traffic noise was present (i.e. the visual stimulus is particularly important at low levels of road traffic noise, while the acoustic stimulus dominates perception at high levels of road traffic noise).

Axelsson *et al.* (2014) conducted a field experiment to investigate the impact of sounds from a large jet-and-basin fountain located in a park in Stockholm (Sweden), in the presence of road traffic noise (same water feature tested by Nilsson *et al.* (2010)). Questionnaires were carried out in five zones around the fountain: zones 1 and 5 were located at 37 m to the north and south respectively of the fountain and close to main roads; zone 3 corresponded to the area close to the water structures and extending around 10 m, whilst zones 2 and 4 corresponded to the intermediate areas. In zones 1 and 5, road traffic noise was dominant, whereas fountain sounds was dominant in zone 3. In zones 2 and 4, road traffic noise and fountain sounds were perceived as equally loud. Results showed that water sounds from the fountain have a positive effect on masking road traffic noise especially in an area close to the water structure (zone 3). However, it worth noting that this area is restricted to 10 m around the fountain, while this extended 20-30 m according to the results obtained by Nilsson *et al.* (2010). Additionally, results of preferences pointed out that people dislike road traffic noise and prefer natural sounds, and this effect is unrelated to sound pressure levels, meaning that natural sounds are preferred to road traffic noise also when their sound pressure levels are equal.

Finally, this section ends by giving a summary of main findings of previous researches that are relevant to the work presented here, as shown in Tables 2.8-2.9-2.10, where all these represent crucial elements to be considered for the design of a water feature. Additionally, this literature review has led in part to a new framework of designable factors that should be considered for the design of water features as illustrated in Chapter 8.

Table 2.8 Main findings obtained from previous studies involved in (a) the mechanisms of water generated sounds, (b) the acoustic characterisation and effects of design parameters on the quality of water sounds.

(a) Mechanisms affecting water sound generation
(1) The physical process of water generating sounds is due to the formation of vibrating bubbles in the liquid (Bragg, 1921).
(2) The direct relationship between the resonant frequency of bubbles and their radius can be used to study the physical phenomenon (Minneart, 1931) (Leighton and Walton, 1987) (Leighton, 1994).

(b) Acoustic characterisation and the effect of design parameters on water sounds'
(1) In general, sounds generated from various water features (waterfalls, streams, falling water and fountains) are dominant in mid-frequencies (most of the energy contained in the 500 Hz - 16 kHz octave bands) (Watts *et al.* 2009) (You *et al.*, 2010) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013).
(2) Water splashing onto hard surfaces, waterfalls and fountains, tend to produce high frequency components, whilst low frequencies tend to be associated to a large flow of water dropping onto water, such as falling water or flowing water, streams and water flowing into cavities (Watts *et al.*, 2009) (You *et al.*, 2010) (Galbrun and Ali, 2013).
(3) Waterfalls can generate low frequencies by increasing the flow rate, whilst the bubbles generated in fountains and cascade are too small so that low frequencies cannot be easily produced by increasing the flow rate (Galbrun and Ali, 2013).
(4) An increase in flow rate results in a logarithmic increase of sound pressure levels generated from different small to medium sized water features (waterfalls, fountain jets and cascades) (Galbrun and Ali, 2013), as well as an increase of loudness (Fastl, 2005) (Galbrun and Ali, 2013).
(5) A relationship was found between psychoacoustic parameters and flow rate of water features: an increase of sharpness with flow rate was observed for a cascade, fountains and jets, but not for waterfalls; conversely, roughness tended to decrease logarithmic for waterfalls, fountains, a cascade and jets (Galbrun and Ali, 2013).

Table 2.9 Main findings obtained from previous studies involved in (a) the perceptual assessment of preferences of water sounds, and (b) the audio-visual interaction.

(a) Acoustic preferences of water sounds in the context of tranquillity and relaxation

(1) Waterfalls sounds are effective maskers of road traffic noise at mid-high frequencies but not at low frequencies (Watts *et al.*, 2009) (You *et al.*, 2010) (Galbrun and Ali, 2013), although improvements in tranquillity can be obtained even for low levels of masking (Watts *et al.*, 2009).

(2) Streams sounds tend to be preferred to fountain sounds (Galbrun and Ali, 2013), which are in turn preferred to waterfall sounds (Galbrun and Ali, 2013) (Rådsten-Ekman *et al.*, 2013).

(3) Water sounds which are perceived to be manmade tend not to be liked (Watts *et al.*, 2009).

(4) Water tends to be the preferred impact material, while flat surfaces made of hard materials are poorly rated (Galbrun and Ali, 2013).

(5) The preferred level of water sound is similar or not less than 3 dB below the road traffic noise level (Jeon *et al.*, 2010) (You *et al.*, 2010) (Galbrun and Ali, 2013).

(6) Water sounds with low sharpness tend to promote relaxation (Jeon *et al.*, 2012) (Galbrun and Ali, 2013).

(b) The impact of audio-visual interaction water sounds' on preferences

(1) Preference scores tend to increase when visual images are included in the tests (Watts *et al.*, 2009) (Jeon *et al.*, 2012).

(2) The visual stimulus is important at low levels of road traffic noise, while the acoustic stimulus dominates perception at high levels of road traffic noise (Hong and Jeon, 2013).

(3) Still water is visually calming, but higher visual preferences tend to occur for upward jets or a mix of different kinds of water features (Nasar and Lin, 2003).

(4) The setting in which water features are placed can greatly affect preferences: greenery tends to be preferred to buildings, as the percentage of natural features at a location is a key factor influencing tranquillity (Pheasant *et al.*, 2008) and preferences (Hong and Jeon, 2013).

(5) The visual effects of vegetation on aesthetic preferences is significant, while those of water features is relatively small (Hong and Jeon, 2013).

(6) The perceived loudness of water sounds is positively correlated with the visual factor 'sky' in the panoramic views of an urban landscape (Liu *et al.*, 2014).

(7) Acoustic comfort of flowing water sounds is positively rated for both small and large distances from the view of the waterscapes (Ren and Kang, 2015).

Table 2.10 Main findings obtained from previous studies involved in (a) the evaluation of perceptual components of water features, and (b) the masking properties of water sounds used over road traffic noise.

(a) The evaluation of perceptual components of waterscapes
(1) Factors related to the acoustic characteristics of water sounds ('freshness') (Jeon *et al.*, 2012) and to the harmony and variety of the soundscape ('overall quality') (Hong and Jeon, 2013), as well as to preferences and emotional responses ('calmness', 'pleasantness') (Rådsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013), have a significant effect on perception.
(2) Factors related to water sounds' quality ('vibrancy') (Jeon *et al.*, 2012) and to the perception associated to the acoustic environment ('eventful', 'spatial impression' and 'acoustic comfort') (Rådsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013), are also identified important elements, but less significant than those listed above.
(3) The factor 'freshness' is positively correlated to preferences when water sounds are used over road traffic noise, while 'calmness' is negatively correlated to preferences (Jeon *et al.*, 2012).
(4) The overall 'pleasantness' increases when highly pleasant water sounds (sea sounds and stream sounds) are added to road traffic noise; less pleasant sounds (waterfall sounds) have however no effect on 'pleasantness', whilst pleasant sounds increase the perceived 'eventfulness' (Rådsten-Ekman *et al.*, 2013).
(5) The factor 'acoustic comfort' considerably influences preference for the overall

(b) The evaluation of masking properties of water sounds used over road traffic noise
(1) Different acoustic zones ('zone of exclusion', 'zone of influence' and 'zone of detection') can be identified around a water features with different levels of masking road traffic noise (Brown and Rutherford, 1994).
(2) In the work of Brown and Rutherford (1994) the 'zone of influence' corresponds to a region of 5-10 m from a large fountain (2 m high, 20 l/sec flow rate, concrete basin 18 m × 7 m); 25-30 m from a large waterfall (6 m high and 11 m wide, 125 l/sec flow rate); and 5 m from a large cascade (20 steps), when they are used over high levels of road traffic noise (65-70 dBA).
(3) A positive effect of water sounds on masking road traffic noise occurs in a region of 20-30 m around a large fountain jet (21 m x 14.5 m) when this is used over road traffic noise level of 65 dBA (Nilsson *et al.*, 2010).
(4) A positive effect of water sounds on soundscape perception is restricted to an area of 5-10 m from a large fountain jet (same water structure used by Nilsson *et al.* (2010)) when this is used over road traffic noise level of 65 dBA (Axelsson *et al.*, 2014).

2.5.8 Discussion

In the European Union, about 40% of the population is exposed to road traffic noise which is inducing adverse consequences to human well-being. The Environmental Noise Directive (END) introduced a common approach intended "to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise" (END/European Communities, 2002). This refers not only to the quieting of already noisy areas, but also to the protection of quiet areas against increases of environmental noise. At first sight the Directive fits firmly within the traditions of noise control, but it is clear that it also contains elements that support soundscape planning. Soundscape planning and noise control are well-known to be different in their approaches and dealing with the acoustic environment. However, these differences suggest that the noise control approach could benefit from soundscape planning, due to the complementary nature of these two approaches which should then both be taken into account by acoustic designers and urban planners. For example, most acoustic descriptors common in noise control and management (e.g. equivalent continuous sound levels or percentile levels L_{01}, L_{50} and L_{90}) are usually considered for the analysis. In the soundscape approach, a correlation between these objective acoustic classical indicators and non-acoustical factors related to the subjective perception would be needed, and would complement traditional noise control engineering.

The soundscape approach originated from the concept of acoustic ecology formulated by Schafer (1977) and Truax (1978). This new concept has been adopted in community noise works as a way to account for noise in the urban or rural environments in a more positive manner and to account for subjective experience. Furthermore, a great impact of soundscape research has been widely recognised, but several studies evolved differently around the world, as well as across disciplines, generating diversity of opinions about the definition and aims related to this new research approach. Several activities in the field of soundscape research showed a great interest in different applications, such as international networks and various research projects across Europe. In this context, a lack of a unique method has been recognised for the soundscape assessment, so that there is a need "to provide a foundation for communication across disciplines and professions with an interest in soundscape". In this context, the standard ISO 12913-1 (2014) provides a common definition of "soundscape" and a conceptual framework related to the process of soundscape assessment.

In soundscape research, particular attention has been paid to evaluate the soundscape quality of outdoor environments by using different methodologies such as socio-acoustical surveys, laboratory listening tests, physiological measurements and soundwalks. Several studies on sound preferences showed a general tendency of people to prefer natural sounds, and the use of 'wanted' sounds over 'unwanted' sounds have been identified as an efficient strategy for improving the soundscape perception. Additionally, it has been demonstrated that individual soundscape perception can be influenced both by acoustical and non-acoustical factors. Considering that the evaluation of soundscape quality is rather complicated, a need to identify the principal perceptual dimensions of a soundscape is seen as crucial, in view of understanding how to design an acoustic environment in relation to people's perceptual reactions. For that reason, the semantic differential technique has proved to be a useful method for the qualitative characterisation of a soundscape.

Previous works based on a semantic differential analysis of the soundscape in outdoor environments showed that the most significant factors affecting perception are mainly related to the emotional responses, whilst aspects related to the sound quality and compositions of the soundscape, as well as social aspects and components related to people' experiences, are still important, but less significant. Because of the complexity involved in understanding and interpreting results related to subjective perception, several efforts have been made in order to evaluate the relationship between perceptual descriptors, preferences and objective acoustic measures of the soundscape. However, further research is still needed to identify a unique correlation between these indicators in order to validate the main findings reported in the literature, and discover 'harmonised' criteria for the perceptual assessment of a soundscape. Furthermore, a better understanding is needed to investigate the semantic components of specific soundscapes such as those dominated by water sounds in presence of 'unwanted' sounds. Only few recent studies (Jeon *et al.*, 2012) (Radsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013) have meticulously evaluated the perceptual components related to perception of water sounds in the presence of road traffic noise.

The audio-visual interaction has been recognised as an important non-acoustical factor affecting the soundscape perception. In particular, findings obtained from previous studies revealed that there is a limited knowledge related to the evaluation of audio-visual interaction of water features. Furthermore, previous works have been limited to the impact of environmental landscape or urban components located within different environments (Jeon *et al.*, 2012) (Carles *et al.*, 1992), rather than the impact of those features on their own (i.e. water features' displays). Additionally, it was also found that the settings in which water features are placed can greatly influence preferences (Pheasant *et al.*, 2008) (Hong and Jeon, 2013) (Liu *et al.*, 2014). In order to avoid the effect of landscape and urban objects, it would be interesting to investigate audio-visual interaction of water features by considering only the visual impact of the features' displays on sound perception, when these are placed over the same natural background.

Different designs of water features can greatly affect the way in which water sounds are perceived, but only few recent studies have examined the physical and perceptual properties of water sounds in detail (Watts *et al.*, 2009) (Jeon *et al.*, 2010) (Nilsson *et al.*, 2010) (De Consoel *et al.*, 2011) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013) (Rådsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013) (Axelsson *et al.*, 2014). Additionally, it is already known that water sounds can vary depending on the type and design of water features, but there is no knowledge about what type of water feature is most effective for masking a specific level of road traffic noise. Therefore, a better knowledge is necessary to be able to integrate the soundscape design of water features as a strategy for future urban planning and design. A study of Brown and Rutherford (1994) focused on defining different acoustic areas around water features with different levels of masking road traffic noise, but this evaluation was limited only to theoretical considerations which were not supported by experimental tests. Additionally, a recent work evaluated the masking effect of fountain sounds used over high levels of road traffic noise (65-70 dBA), showing a positive effect of water sounds on soundscape perception in a region 20-30 m around the water structure where the fountain sound was equally loud or louder than the road traffic noise (Nilsson *et al.*, 2010). However, this analysis was limited to a single type of water feature such as a large fountain jet, and water sounds' quality was evaluated with respect only to the perceived loudness of sounds. Moreover, Axelsson *et al.* (2014) investigated the impact of sounds from a jet-and-basin fountain (same water structure used by Nilsson *et al.* (2010)) on soundscape quality in an urban park. It was found that the fountain had a positive effect on improving soundscape perception in a zone close to the feature but this was restricted to approximately 10 m less than the region identified by Nilsson *et al.* (2010) (Axelsson *et al.*, 2014). This works focused on investigating the masking properties of few types of large sized water features located in urban settings characterised by only one range of road traffic noise levels, and this analysis has been made without taking into account the context for which soundscape perception can be improved (e.g. relaxation/tranquillity or freshness/vibrancy). Therefore, the research presented in this thesis will focus on evaluating the effect of different types of water features in improving soundscape perception for different ranges of road traffic noise levels by considering the context and the intended use of the spaces for which water features should be designed. Additionally, the development of sound maps for different type of water features will be examined as an efficient mean for landscape and urban planning.

2.6 Conclusions

The design of water features has always been focused on various aspects related to aesthetic/functional criteria and physical/technical components, as well as elements associated to the environmental conditions, with little attention given to the auditory aspects of water generated sounds. Within that context, the soundscape approach (physical characteristics and mental perception of the aural environment) provides an innovative and strategic tool for designing water features from an acoustic point of view, aiming at combining designable factors with objective acoustic measures and the subjective perception of the acoustic environment.

A review of previous works that are relevant to the research presented here, has shown that there is a need to reduce improve quality of life and comfort in cities or rural settings due to the high exposure to environmental noise, as highlighted by the Environmental Directive (END). In this context, the importance of the soundscape approach and planning has been recognised as a mean to consider noise as a resource in the environment, as well as to account for subjective experience. Furthermore, introducing positive sounds over ‘unwanted’ sounds has been identified as a potential strategy for enhancing the soundscape quality. Because of the complexity of the soundscape approach, being involved in multidisciplinary fields of research, a diversity of opinions and methodologies used for the assessment and design of a soundscape emerged among researchers. In this context, the ISO 12913-1 (2014) has represented a first stage towards a process of standardisation for soundscape research.

In relation to the work presented here, the literature has shown that the acoustic use of water features has been widely identified as a potential tool for masking road traffic noise due to their inherent positive qualities (Kang, 2007) as well as their distracting effects as ‘wanted’ sounds (Watts *et al.*, 2009). The soundscape approach has been extensively used to analyse water features, but only few recent studies have examined the physical and perceptual properties of water sounds in detail (Watts *et al.*, 2009) (Jeon *et al.*, 2010)

(Nilsson *et al.*, 2010) (De Consoel *et al.*, 2011) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013) (Rådsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013) (Axelsson *et al.*, 2014).

This previous research showed that there is a limited knowledge about the audio-visual interaction of water features, as well as the perceptual components affecting perception of water sounds. The approaches and methodologies used so far have largely focused on acoustical preferences, with little attention paid to visual preferences. Additionally, the evaluation of categorisation and evocation properties of water sounds would be also needed in order to investigate their potential impact on the subjective perception. With regard to the masking effects of water sounds used over road traffic noise, only few previous works have meticulously examined water features in view of providing evidence-design solutions. In this context, a better understanding of what type of water features is most effective for masking a specific level of road traffic noise would be needed: this analysis should be also extended to different types of waterscapes located in different noise settings as well as to combinations of water features.

In conclusion, the analysis of main findings related to the acoustical and perceptual assessment of water sounds identified the gaps in the literature, and helped to give justifications for the research presented here and to define its objectives. In particular, this thesis aimed at developing a better understanding for the design of water features which can be used in outdoor spaces where road traffic noise is audible. The audio-visual tests aimed at identifying which water sounds and visual displays of water features are more suitable for improving relaxation, as well as investigating the relationship between acoustic/psychoacoustic parameters and subjective perception of water sounds. Furthermore, the semantic differential test aimed at identifying the principal semantic factors affecting preferences of water sounds were evaluated by using a semantic differential test, and investigating the relationship between semantic components and acoustic/psychoacoustic parameters as well as preferences of their corresponding water sound. Furthermore, tests on the categorisation and evocation of water sounds aimed at understanding how these aspects can affect preferences of water sounds. Additionally, the development of sound maps aimed at examining the sound pressure level effectiveness of small to medium sized water features used over different ranges of road traffic noise levels, within the context of relaxation, as well as to identify the optimal distances from the water features tested where relaxation can be promoted.

CHAPTER 3

Methodology for laboratory tests

3.1 Introduction

This chapter describes the methodology used for the research. The water features examined are illustrated, including details of water sounds and visual representation of their displays. Finally, the methodology used for the perceptual assessment of water features used over road traffic noise is explained, including the statistical methods applied to data analysis. At the end, conclusions are illustrated.

3.2 Water features used

This section illustrates all details relating to the different types of water features used in the research project presented here, including their design and acoustical/psychoacoustic characteristics, as well as the representations of their visual displays.

The waterscapes examined include small to medium sized water features that can be installed in outdoor settings (e.g. gardens and parks) as well as in indoor environments such as hotels' lobbies, restaurants and offices. The water features used in the experiment were constructed in the laboratory by Galbrun and Ali (2013), with the exception of natural shallow streams which were tested in the field. A variety of water features were obtained by varying design parameters such as the waterfall's width, height of falling water, flow rate and impact material.

Ten different water features have been selected from this pool of data to represent a wide range of water structures: a waterfall with a plain edge (PEW), a waterfall with a sawtooth edge (SEW), a waterfall with an edge made of small holes (SHW), a fountain with 37 upwards jets (FTW), a foam fountain (FF), a dome fountain (DF), a large jet (LJT), a narrow jet (NJT), a cascade with four steps (CA) and a natural shallow stream (ST). These features can be classified in three different categories such as waterfalls, fountains with upwards jets, and streams. The large jet (LJT) has been previously categorised by Galbrun and Ali (2013) as a stream due its shallow and irregular distribution of water as suggested: the presence of a low pressure at the large opening of its nozzle generates a unsteady operation of the pump and a high value of L_{A10}-L_{A90} (Galbrun and Ali, 2013). In the present research, LJT has been considered as belonging to two categories (fountain and stream) in view of carrying out a comprehensive analysis of the qualitative categorisation of water features (details are given in Chapter 5). The design properties and acoustic/psychoacoustic parameters of each water feature are illustrated in Table 3.1 where the numbers in italic correspond to parameters calculated for sounds including both water sounds and road traffic noise. The road traffic noise used in the listening tests consisted of dense road traffic with low temporal variability, which was recorded at 200 m from the centre of a busy motorway (M8 Edinburgh – Glasgow, UK) (Galbrun and Ali, 2013).

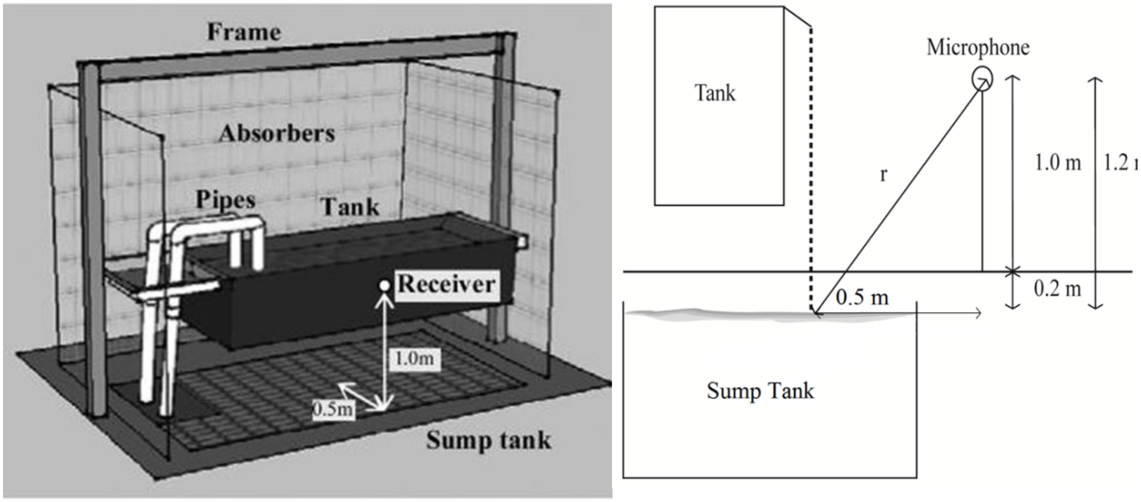
It is also worth mentioning that water was the main impact material chosen for the water features considered in the study with the exception of CA, FF and ST. Compared to the twelve features examined by Galbrun and Ali (2013), the hard impact surface for the 37 jets fountain (FTS) and the waterfall with small holes (SHC) were excluded, as it was found that water tends to be the preferred impact material compared to hard materials such as concrete and stones in the auditory tests (Galbrun and Ali, 2013).

3.2.1 Water sounds

All water sounds were measured by using a test structure built in the laboratory, whilst sounds from the natural shallow stream were measured in the field (Figure 3.2) (Galbrun and Ali, 2013). The test structure consisted of a sump tank encased in the floor and into which water falls (2.0 m long × 1.2 m wide × 1.2 m high) and a tank fixed at a higher level for waterfalls' testing (1.5 m long × 0.5 m wide × 0.5 m high) as shown in Figure 3.2(a) (Galbrun and Ali, 2013). The tank was attached to a frame which allowed it to reach a maximum height of 2.5 m above the floor level. Two submersible pumps with low noise level were placed in the sump tank and used to circulate water to the upper tank or to fountains' extensions with a variable flow rate. Sound reflections from adjacent surfaces were minimized by installing absorption panels around the structure. Audio recordings were carried out by Galbrun and Ali (2013) with a digital sound recorder (Zoom H4n) connected to Brüel and Kjaer Type 4190 ½ microphones attached to a dummy head. Measurements were carried out at a distance of 0.5 m from the centre section of the basin (impact area of falling water) and 1 m above floor level (Galbrun and Ali, 2013). Considering that measurements were carried in an enclosed spaces (a laboratory with very large space of dimensions 20 m × 15 m × 7 m), this receiver

Table 3.1 Properties of water sounds and road traffic noise used in the audio-visual tests. Acoustic and psychoacoustic parameters of the sounds normalised at 55 dBA are also included. Category 1= waterfall, 2 = fountain, 3 = stream. The numbers in italic correspond to parameters calculated for sounds including both water sounds and road traffic noise (Galbrun and Ali, 2013).

Sound code	Water feature type + Category	Impact material	Flow rate (l/min)	Height(m) – Width(m)	L_{A10}-L_{A90} (dB)		L_{Ceq}-L_{Aeq} (dB)		Sharpness (acum)		Roughness (asper)		Pitch strength	
PEW	Plain Edge Waterfall-1	Water	120	1.0 – 1.0	1.10	*1.40*	-0.30	*2.8*	1.98	*1.70*	0.03	*0.04*	0.04	*0.07*
SEW	Sawtooth Edge Waterfall-1	Water	30	0.5 – 1.0	1.00	*1.60*	-0.10	*2.7*	1.92	*1.59*	0.05	*0.05*	0.10	*0.07*
SHW	Small Holes Waterfall-1	Water	30	0.5 – 1.0	0.70	*1.40*	-1.00	*2.5*	2.23	*1.71*	0.02	*0.04*	0.09	*0.08*
FTW	Fountain (37 jests)-2	Water	30	-	1.40	*1.50*	-0.90	*2.7*	2.21	*1.67*	0.07	*0.08*	0.10	*0.08*
FF	Foam Fountain-2	Stones *and* Boulders	30	-	2.30	*1.60*	-0.20	*2.8*	1.91	*1.61*	0.09	*0.09*	0.05	*0.07*
DF	Dome fountain-2	Water	40	-	1.19	*1.40*	-0.95	*2.5*	2.16	*1.70*	0.05	*0.05*	0.11	*0.08*
NJT	Narrow jet-2	Water	15	-	1.90	*1.60*	-0.90	*2.5*	2.09	*1.67*	0.19	*0.16*	0.07	*0.08*
LJT	Large jet (25 mm nozzle)-2/3	Water	15	-	4.90	*2.10*	4.90	*2.9*	1.73	*1.42*	0.28	*0.19*	0.08	*0.07*
CA	Cascade (4 steps)-3	Stones (pebbles)	15	-	1.20	*1.40*	-1.30	*2.7*	2.21	*1.71*	0.10	*0.09*	0.05	*0.08*
ST	Natural Shallow Stream -3	Stones *and* Water	2400	-	2.40	*1.70*	1.40	*2.5*	1.99	*1.61*	0.29	*0.21*	0.06	*0.08*
RTN	Road Traffic Noise	-	-	-	2.7		7.8		1.04		0.03		0.09	



3D representation Cross section

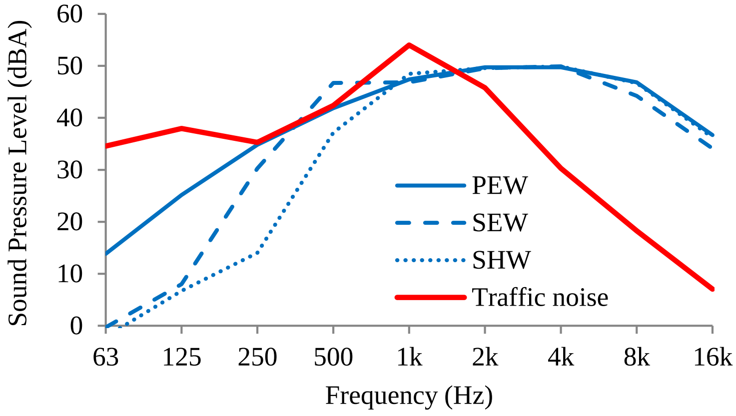
(a) Laboratory setting

(b) Field setting (natural shallow stream)

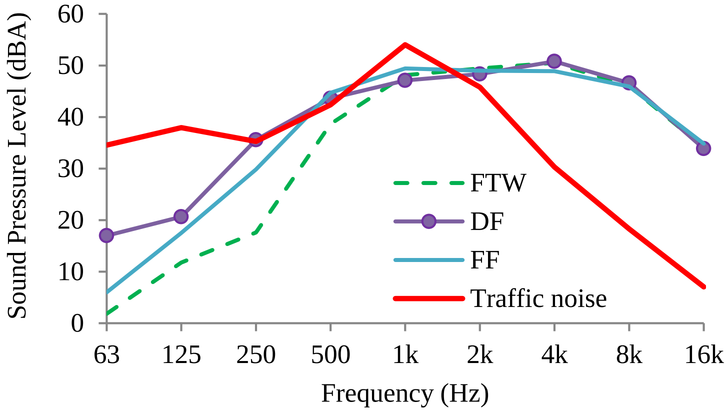
Figure 3.1 Setting used for sound pressure level measurements and audio recordings in the laboratory (a) and field (b) (Galbrun and Ali, 2013).

position was identified as an acceptable source-receiver distance (0.5 m) for which the influence of reflected sound should be negligible on results (Galbrun and Ali, 2013). On the other hand, in the case of the natural shallow stream, measurements were carried out at 2 m from the edge of the feature tested and 1 m above water (Figure 3.2 (b)). These recordings were also used for calculating psychoacoustics parameters through Matlab using the module *PsySound3* (sharpness, roughness and pitch strength) (Ali, 2012). The following default time steps were used in the calculations: 2 ms for sharpness, 186 ms for roughness and 10 ms for pitch strength (Cabrera et al., 2008). Acoustic and psychoacoustic parameters for water sounds normalised at 55 dBA are given in Table 3.1.

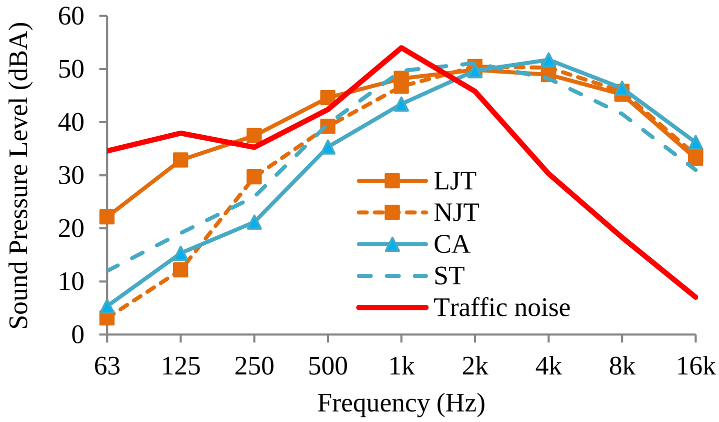
With regard to the acoustic characteristics of water features tested in this thesis, results in terms of sound spectra showed that road traffic noise is dominated by low frequencies whereas mid–high frequencies are predominant in water sounds (most of the energy contained in the 500 Hz-16 kHz octave bands) (Figure 3.1) (Ali, 2012).



(a) Waterfalls.



(b) Fountains.



(a) Jets, cascade and stream.

Figure 3.2 Normalised spectra of measured road traffic noise (200 m distance between motorway and receiver) and measured water sounds used in the audio-visual tests. (Ali, 2012). (Refer to Table 3.1 for acronyms of water features).

This suggested that low frequencies cannot be easily generate by water sounds when compared to road traffic noise, as previously pointed out by Watts *et al.* (2006), You *et al.* (2010) and Galbrun and Ali (2013) and illustrated in the literature review of Chapter 2.

Binaural audio recordings of 20 s were made for each water feature considered in the perceptual tests. Additionally, an average period of 20 s for recordings was considered large enough to cover the operation cycles of water features (i.e., steady water sounds for all water features tested with the exception of the large jet, LJT). Samples of 7 s were then extrapolated from the binaural audio recordings for each water feature considered, and were used for laboratory tests as well as for determining the acoustic quality descriptors of water sounds (the short time period of 7s was considered enough to calculate parameters of water sounds due to the steady nature of sounds). In particular, these were used as audio stimuli for the audio-visual tests, the semantic differential tests and the qualitative analysis for water sounds' categorisation and evocation (Chapters 4 to 6), and played through closed studio headphones Beyerdynamic DT 150. Additionally, measured values of L_p available from previous research (Galbrun and Ali, 2013) were used for the development of sound maps for the water features considered in this thesis, as shown in Chapter 7.

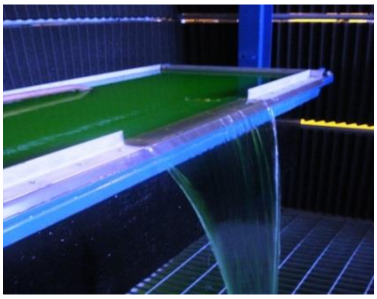
3.2.2 Displays of water features

The visual representation of water features' displays consisted of images where water features were placed over the same natural background. A garden within the campus of Heriot-Watt University was identified as a suitable landscape representative of a garden or park with vegetation (Figure 3.3). All images were developed using *Adobe Photoshop CS3* photo editing software. The displays of water features reproduced as images, were as similar as possible to the actual features of Table 3.4 which were tested in the laboratory (Figure 3.4) (with the exception of the natural shallow stream measured in the field). These images were used for investigating the audio-visual impact of the water features in the perceptual preference tests (Chapter 4), and can be visualised in Figure 3.5.

The existing body of research involved in the study of audio-visual interaction has focused on laboratory experiments where visual images were taken from existing landscapes or urban environments which had the potential to be matched with the sound stimuli. In the research presented here, the visual impact of different displays of water

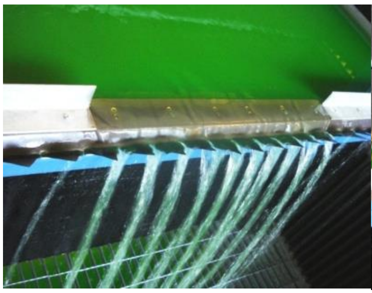
Figure 3.3 Garden within the campus of Heriot-Watt University used as a representative landscape for the audio-visual tests.

features was examined rather than the surrounding environment. Additionally, a natural green scene was chosen as background of the images, as the percentage of natural features in visual stimuli for the laboratory was demonstrated to be a positive factor associated with how tranquil an environment was perceived to be (Pheasant et al., 2008). Although the use of these images was limited to a garden scene with only greenery, additional natural elements such as the sky were excluded from the analysis as previous research pointed out that these can be effective landscape elements influencing soundscape perception (Liu *et al.*, 2014). However, further research would be needed to investigate the effect of different natural visual elements (e.g., the sky, the presence of animals) of a landscape on the audio-visual interaction of different waterscapes. It is also worth noting that the current work was limited to the use of still images for the visual materials in the audio-visual tests. However, previous research showed that there were no significant differences when perception of still images was compared with videos in laboratory tests (Hong *et al.*, 2010). Additionally, further work will be needed in order to examine differences in preferences between still and moving scenes for exploring the audio-visual interaction of water features.



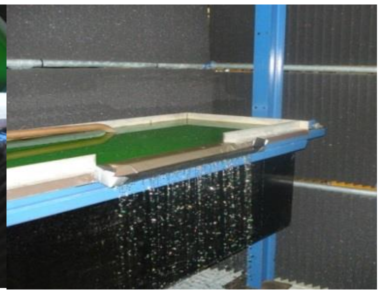
(a) Plain edge waterfall

(PEW)



(b) Sawtooth edge waterfall

(SEW)



(c) Small holes waterfall

(SHW)

(f) Foam fountain

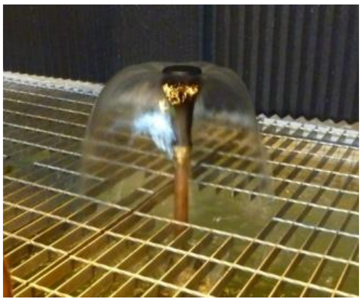
(FF)

(d) Fountain- 37 jets

(FTW)

(e) Narrow jet

(NJT)



(g) Dome fountain

(DF)

(h)Cascade - 4 steps

(CA)

(i) Large jet

(LJT)

Figure 3.4 Water features constructed in the laboratory (Ali, 2012).


(a) Plain Edge Waterfall (PEW)


(b) Sawtooth Edge Waterfall (SEW)


(c) Small Holes Waterfall (SHW)


(d) Fountain with 37 upward jets


(e) Dome fountain (DF)


(f) Foam fountain (FF)


(g) Large jet (LJT)


(h) Narrow jet (NJT)


(i) Cascade- 4 steps (CA)


(j) Natural shallow stream (ST)

Figure 3.5 Visual representation of displays of water features: images used in audio-visual tests.

3.3 Perceptual assessment of water features used over road traffic noise

In this section, a brief overview of the methodology used for the perceptual assessment of water features used over road traffic noise is given, and the statistical methods applied for data analysis are then described. Further details about the test procedures used and measurements are given in Chapters 4 to 6.

3.3.1 Methodology

The perceptual assessment of water features used over road traffic noise was carried out through the use of laboratory tests. These included audio-visual tests in view of investigating the audio-visual impact on preferences (Chapter 4), as well as semantic differential tests, categorisation and evocation of water sounds and visual categorisation of displays of water features in view of evaluating the qualitative perception of water features (Chapters 5 and 6). All these tests were undertaken within the context of relaxation and peacefulness in outdoor environments where road traffic is audible for the ten different waterscapes.

The tests were carried out in the anechoic chamber of the School of Energy, Geoscience, Infrastructure and Society of Heriot-Watt University, with the exception of the test for the visual categorisation which was carried out through an online survey. During the laboratory experiments, audio and visual stimuli were presented from a computer through closed headphones (Beyerdynamics DT 150) and a widescreen LED monitor (Samsung S27A350H, 27 inch) respectively (Figure 3.6).

Three different tests were carried out using a paired comparison method: a listening test, a visual test and an audio-visual test. The aim was to identify the preferred water sounds, the visual impact of water features' displays, and the audio-visual interaction between preferences. These tests were undertaken for the ten different waterscapes of Table 3.1 when they were used over road traffic noise.

A semantic differential test was then carried out in view of sound characterisation for the ten water features tested (Table 3.1). Furthermore, the test for the categorisation of water sounds and evocation was used to examine the identification of sounds and evocation. These were based on audio materials only (same audio materials used for the listening test) and a questionnaire which was used to evaluate subjects' responses.

Figure 3.6 Laboratory setting used for the experiments.

The test for the visual categorisation of water features aimed at understanding whether the water features' displays appeared natural or manmade; this was based on visual material only and was carried out through an online survey.

Audio-visual tests

Audio-visual tests were carried out in view of evaluating the multi-sensory effects of preferences of water sounds, and these included three different paired comparison tests (a listening test, a visual test and an audio-visual test) which were undertaken in different sessions. Audio stimuli consisted of water sounds combined with road traffic noise (Table 3.1), while visual stimuli corresponded to the images presented in section 3.3.2. The audio-only test was based on audio material only; the visual-only test was based on visual material only, and the audio-visual tests included a combination of audio and visual materials.

During the experiments, pairs of sounds were presented in stereo format one after the other (i.e. diotic listening) through closed headphones (Beyerdynamics DT 150) and visual stimuli were shown from a widescreen LED monitor (Samsung S27A350H, 27 inch) respectively. The monitor was located on a desk close to the seating position of participants, in order to ensure a high sense of involvement in the visual scene. Binaural signals used for the audio-visual tests were derived from sound files including road traffic noise and water sounds, and the original SPLs of the corresponding sounds used in this thesis can be found in Ali (2012). The binaural signals were produced using the audio editing software Cubase LE 4 that allowed combining different sound recordings, as well as calibrating the signals of each recording (Ali, 2012). Calibration of the signals was made using a custom made head and torso model with microphones placed inside the ears and connected to a sound level meter, and with closed headphones Beyerdynamic DT 150 used to play the signal (Ali, 2012).

The audio stimuli consisted of water sounds that were played at 55 dBA. The same level was used for water sounds and road traffic noise as it was shown that a difference of 0 dB between water sounds and traffic noise tend to be preferred (Galbrun and Ali, 2013) (Jeon *et al.*, 2010) (You *et al.*, 2010). The level used for the tests was 55 dBA, as it characterizes an outdoor environment that can significantly benefit from the use of water features, being not too quiet (no need for masking sounds) and not too noisy (masking sounds irrelevant for relaxation). In addition, previous research showed that no significant differences were observed in audio preferences of water sounds presented with road traffic noise fixed at 55 dBA, 70 dBA or 75 dBA (You *et al.*, 2010) (Hong and Jeon, 2013).

The paired comparison method was adopted to evaluate stimuli preferences in uni-modal and bi-modal sensorial conditions. Three different paired comparison tests were carried out to assess the interaction between the acoustical and visual stimuli: an audio-only test, a visual-only test, and an audio-visual test. The paired comparisons produced ordinal data that was appropriate for ranking preferences. This method has often been used in soundscape research (You *et al.*, 2010) (Jeon *et al.*, 2010) (De Coensel *et al.*, 2011) (Galbrun and Ali, 2013) and was preferred to rating scales because of its simplicity and greater accuracy (Mantiuk *et al.*, 2012) (for more details on the pair wise methodology, refer to section 2.2.7 of Chapter 2). The audio-only test was based on audio material only and consisted of two parts: the first part was carried out in view of understanding the preferred water sounds in the presence of road traffic noise, whilst the second part was a semantic differential test which is illustrated in Chapter 5. The visual-only test was based on image material only and was carried out in order to investigate the preferred water features' display, whilst the audio-visual tests included a combination of audio and visual material and aimed at evaluating the impact of audio-visual interaction on preferences.

The paired comparison method was adopted to evaluate stimuli preferences for the three conditions tested. Each test included forty-five comparisons which consisted of seven seconds of stimulus 1, one second of silence, seven seconds of stimulus 2, and three seconds of silence before the next pair was played. Ten paired comparisons were repeated in the audio-only test, to identify the consistency of participants. Comparisons were randomised to avoid order effects, i.e. different orders of stimuli were obtained for each subject. However, the same sequence of randomised comparisons was used for each subject in the three test conditions (audio-only, visual-only and combined audio-visual). After listening to each comparison, participants were asked to select the stimulus that they preferred in terms of relaxation and peacefulness. After every ten paired comparisons, participants could independently decide to take a break before continuing the test. Each test lasted typically thirty minutes per subject, including instructions and breaks. All tests were carried out over two different sessions. The first session consisted of two tests and lasted around one hour per subject. Firstly, this included the audio-only test on preferences followed by a break and secondly, the semantic differential test and the qualitative categorisation of water sounds, which are presented in Chapters 5 and 6. The visual-only and the audio-visual tests were carried out over another session that lasted around 60 minutes including the break between the two tests.

Semantic differential test

The semantic test was carried out following the first part related to sound preferences and typically lasted 30 minutes per subject, including instructions. The ten water sounds (PEW, SEW, SHW, FTW, DF, FF, LJT, NJT, CA and ST, see Table 3.1 for details and acronyms) were played individually (7 seconds of audio recording) through closed headphones (Beyerdynamics DT 150). For each sound, participants had to answer a questionnaire (Appendix D) after listening to each individual sound as many times as they wanted. In order to assess water sounds' characterisation, questions based on a five-point verbal scale were used for the qualitative analysis. Additionally, participants were instructed about the meaning of each semantic descriptors selected for this analysis (e.g., a sharp sound corresponds to a gunshot or sharpening a knife).

Based on a review of previous studies on semantic differential analysis of soundscapes (Raimbault *et al.*, 2003) (Fastl, 2005) (Fastl, 2006) (De Coensel and Botteldooren, 2006) (Guillén and López Barrio, 2007) (Davies *et al.*, 2009) (Jeon *et al.*, 2010) (Kang and Zhang, 2010) (Axelsson *et al.*, 2010) (Jeon *et al.*, 2011) (Cain *et al.*, 2011) (Jeon *et al.*, 2012) (Radsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013) (Jeon *et al.*, 2014) (Hong and Jeon, 2015), pairs of antonymous adjectives as well as a five numerical point scale were identified for the qualitative analysis of individual water sounds. Previous research showed that different factors can affect sound perception. These factors were identified as pleasantness, comfort, and relaxation, satisfaction, freshness, temporal variation, vibrancy, communication, eventfulness, spatial dimension, naturalness, familiarity, activity due to the audible presence of human beings, daily life, social aspects, timbre, sound marks and the presence of mechanical sounds. In the study presented here, the qualitative descriptors of water sounds selected after this review were: relaxation (relaxing-stressful), naturalness (natural–artificial), familiarity (familiar–unfamiliar), freshness (refreshing–weary), perceived sharpness (sharp–flat), perceived roughness (rough–smooth), speed (fast-low), envelopment (enveloping-directional) and temporal variation (unsteady-steady).

Relaxation, familiarity and freshness were selected in view of understanding how components related to emotional attributes might influence water sound's perception in the context of relaxation and peacefulness. In addition, naturalness was included in order to study how different water features made subjects think of natural or artificial sounds.

Furthermore, perceived sharpness, perceived roughness, temporal variation, speed and envelopment were investigated in order to understand how individual physical properties of sounds can drive subjective perception of different. The latter choice was also made in view of allowing a comparison between results obtained in terms of perceptual properties of sound and the physical parameters measured for the corresponding water sounds tested.

Each pair of antonymous adjectives was assigned a five point rating scale (e.g. very relaxing, relaxing, neither relaxing nor stressful, stressful, very stressful). This scale was identified as the most appropriate in view of evaluating individual water sounds, according to ISO-1566 (2003).

Categorisation and evocation of water sounds

In view of examining identification of water sounds, participants were asked to indicate which type of water feature the sound made them think of (waterfall, fountain, natural stream, none of these), as well as to indicate if the water sound could be associated to a manmade sound (e.g. water falling into a drain/container or a tap) or rainfall (see Appendix D). Evocation was also examined by asking the following open-ended question: "*If the sound evokes anything to you, please explain what it makes you think of*". Additionally, visual categorisation of different water features was investigated by carrying out an online test which lasted around 10 minutes. It was developed using a Google Docs form (Appendix E). This visual test included the displays of the ten water features corresponding to the waterscapes used in the audio-visual tests, and aimed at understanding whether the water features' displays appeared natural or manmade. Subject were asked to familiarise themselves with the water features tested by looking at the ten images presented before starting the test. Once they felt comfortable with the procedure, participants were requested to focus their attention on the water features' displays and select the response for each of the ten images by ticking the box corresponding to the categorisation: natural, manmade or neither.

3.3.2 Participants

Forty-four participants (twenty-three females and twenty-one males of age distribution 24-44 years, average age 30.5 years and standard deviation 5.33 years) who reported normal hearing ability took part in all tests which were typically carried out over two sessions. Before each test, all participants were asked to confirm that they had no hearing difficulties (e.g. tinnitus). All participants were recruited among students and researchers working at Heriot-Watt University, and the sample was representative of varied cultural groups. During each test, participants were instructed that they had to imagine being relaxing in a garden or balcony where they could hear (for the audio-only test) / see (for the visual-only test, and both senses for the audio-visual test) water features. At the end, they were asked to answer a questionnaire (Appendices A to C) by ticking boxes with their preferences. Tests were carried in the anechoic chamber of the School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University in view of ensuring a low level of background noise (around 21 dBA during tests, including noise from the computer used). All participants took part in the audio-visual tests, the semantic differential test as well as the categorisation and evocation of water sounds used over road traffic noise.

3.3.3 Statistical methods used for data analysis

Results obtained from the perceptual assessment of water features were then evaluated by using statistical analysis through the *SPSS* software. Non parametric tests were used to examined data obtained from the laboratory tests. A probability level less than 0.05 ($p < 0.05$) was chosen to evaluate the statistical significance of results. The Mann-Whitney (U) test was used in order to evaluate statistical differences in response among different genders (group 1 = male and group 2 = female) and different ages (group 1 = age ≤ 30 years and group 2 = age > 30 years, age distribution ranging from 24 to 47 years) for the audio-visual tests (details can be found in Chapters 4 to 6). Significant differences in responses among different cultural groups (group 1 = “White”, group 2 = “Middle-Eastern” and group 3 = “Asian”) were evaluated through the use of the Kruskal-Wallis (H) test (details can be found in Chapters 4 to 6). The t-test was considered to evaluate the mean differences in preference scores obtained from the audio-only, visual-only and audio-visual tests (details can be found in Chapter 4). Additionally, correlations between variables were examined using Spearman's test: this test determined the correlations between preferences obtained from perceptual tests in audio-only, visual-only and audio-visual conditions; and it was also used to calculate correlations between preferences and acoustic/psychoacoustic parameters of water sounds, as well as preferences and semantic components (details can be found in Chapters 4 to 6). In the research presented here, a principal component analysis (PCA) was used as a method for variable-reduction: this was used in order to evaluate the main principal components for scores obtained from the semantic differential test (details can be found in Chapter 5). In addition, the statistical analysis of concordance based on the Kendall's coefficient (W) was used to examine the degree of agreement in preference scores among participants in the audio-visual tests (where $W = 1$ there is unanimous agreement between subjects and, as a rule of thumb, if $W > 0.8$ there is good agreement between subjects (Field, 2009)). A cluster analysis was then adopted as a method for identifying homogenous groups of preferences (clusters) obtained from the laboratory tests in uni-modal and bi-modal sensorial conditions; and it was also carried out due to the low agreement (W Kendall's coefficient concordance < 0.8) found among participants in rating preferences in audio-visual tests (details can be found in Chapter 4). Although both cluster analysis and discriminant analysis (also known as supervised classification) classify objects (or cases) into categories, the purpose of cluster analysis is to classify data of previously unknown structure into meaningful groupings (Fraley and Raftery, 2000) (Burns and Burns, 2008). This means that the number of clusters in discriminant analysis are assumed to be known (Burns and Burns, 2008). In this current work, a cluster hierarchical analysis was preferred to a discriminant analysis as the purpose was to use a tool for which no assumptions should be made about the group membership for classifying data for the cases used to derive the classification rule. In the research presented here, a binary logistic regression was carried out to estimate the stochastic relationship between audio-only preferences and semantic components/attributes (details can be found in Chapter 5). Finally, a multiple linear regression was used in order to validate the findings obtained from the binary logistic model and to evaluate the direct positive relationship between audio-only preferences and semantic component 'emotional assessment' (details can be found in Chapter 5).

3.4 Conclusions

This chapter illustrated the methods used in the research presented here; this included an overview of the audio and visual characteristics of water features tested as well as the perceptual assessment of water features used over road traffic noise.

The water features examined have been described in detail, including how these structures were obtained by varying design parameters such as the waterfall's width, height of falling water, flow rate and impact material (Galbrun and Ali, 2013). The procedure of water sounds' measurements have been also described, together with the corresponding acoustic and psychoacoustic parameters. Additionally, all details related to the visual representation of water features' display have been shown.

The methodology used for the perceptual assessment of water features used over road traffic noise has been described with the statistical methods applied to data analysis.

It is also worth noting that the methodology used for the development of sound maps has not been explained here, as this can be found in great details in Chapter 7.

CHAPTER 4

Audio-only, Visual-only and Audio-visual Preferences of Water Features used over Road Traffic Noise[1]

4.1. Introduction

The analysis presented in this chapter illustrates the main findings obtained with regard to the perceptual assessment of a wide range of waterscapes in the presence of road traffic noise. The objectives of this analysis were to identify the preferred water sounds, the preferred displays of water features, and to examine the audio-visual interaction on preferences for improving relaxation within gardens and parks where road traffic noise is audible; as well as to investigate the relationship between acoustic/psychoacoustic parameters of water sounds and the corresponding preferences (objectives 1 and 2, as shown in section 1.3 of Chapter 1). Results obtained from the audio-visual tests are presented in terms of audio-only, visual-only and audio-visual preferences. The audio-visual interactions on preferences is investigated in order to understand the impact of different water features on subjective perception in view of improving relaxation and peacefulness where road traffic noise is audible. The chapter starts by illustrating the assessment of preferences in different sensorial conditions. Correlations are also presented between audio-only vs. visual-only vs. audio-visual preferences. A principal component analysis is illustrated in order to identify the main components affecting subjective perception. Additionally, the analysis of correlations between preferences and acoustic/psychoacoustic parameters is shown in view of understanding the influence of physical properties of sounds on preferences. Finally, a critical discussion is given at the end of the chapter.

4.2 Preferences from audio-only, visual-only and audio-visual tests

Audio-visual tests were carried out in view of evaluating the multi-sensory effects of water sounds perception in the presence of road traffic noise. The visual impact of the water features' displays has been examined using images of the water features' displays placed over a single natural background, whilst auditory perception was based on the

[1]Some sections of this chapter are based on the paper: L. Galbrun and F.M.A. Calarco, "Audio-visual interaction and perceptual assessment of water features used over road traffic noise", *J. Acoust. Soc. Am.*, **136(5)**, 2609–2620, (2014).

corresponding water sounds recorded in the laboratory (with the exception of one feature measured in the field). All tests were carried out in view of improving the soundscape perception in terms of relaxation and peacefulness in outdoor spaces where road traffic noise is audible.

The water sounds and road traffic noise used in the tests are those illustrated in Chapter 3 (section 3.2). In the study presented here, ten water sounds have been selected to represent a wide range of water sounds, including sounds from waterfalls, fountains with upward jets and streams. Detailed information on audio materials used for these tests can be found in Table 3.1, where the design properties and acoustic/psychoacoustic parameters are illustrated 3.1 (Chapter 3). Visual stimuli consisted of ten images in which the different displays of water features displays were placed over the same natural background. These images can be found in Chapter 3 (section 3.2.2). The test procedure and methods used can be found in section 3.4.1 of Chapter 3.

Thirty-eight participants (nineteen females and nineteen males) passed the consistency test (judgements within 95% confidence interval) and were retained for the analysis of results. The age distribution of participants ranged from 24 to 47 years (mean 30.1 years and standard deviation 4.47 years). The cultural groups were composed of nineteen "White", four "Asian", fourteen "Middle Eastern" and one "African". Results, discussed below, have been expressed in terms of normalised preferences based on a ± 2 scale (where -2 means "never preferred" and + 2 means "always preferred"). Scale values were calculated by normalising the number of times a waterscape was chosen in the paired comparisons (0 to 9, number of paired comparisons per waterscape) to an arbitrary -2 to +2 scale. More complex comparative scales (such as Thurstone's law) were not used, as statistical comparisons between scale values were not sought (normalised values being considered sufficient for the analysis of preferences). The normalised preferences were calculated for the audio-only, visual-only and audio-visual tests.

4.2.1. Audio-only preferences

The results from the audio-only test showed that the preferred water sounds are the natural shallow stream (ST), the fountain made of 37 upward jets (FTW) and the cascade with four steps (CA) (Figure 4.1). By contrast, the least preferred water sounds were the waterfall with an edge made with small holes (SHW), the single jet with a narrow nozzle (NJT) and the waterfall with a plain edge (PEW). Additionally, a significant strong and positive correlation was found between audio-only preferences and objective categories

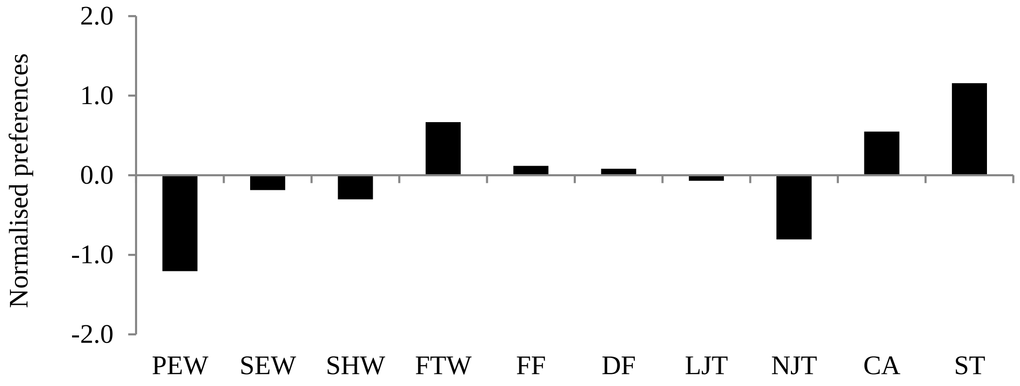


Figure 4.1 Normalised preferences for the audio-only test (refer to Table 3.1 for acronyms and details of water features).

of water features (Spearman test, $\rho = 0.77$, $p < 0.01$ for LJT = category 2;$\rho = 0.67$, $p < 0.05$ for LJT = category 3). These results confirm the findings obtained by Galbrun and Ali (2013) according to which natural shallow stream sounds tend to be preferred to fountain sounds which are in turn preferred to waterfall sounds. A statistical analysis of the results showed no significant differences in responses between different ages and genders (Mann-Whitney test, p > 0.05). However, significant differences were found among different cultural groups for SHW, PEW, FF, DF, and LJT (Kruskal-Wallis test, p < 0.05). Additional analysis showed a small effect sizes between different cultural groups in the case of SHW, PEW, DF and LJT (Cohen test, $d = 0.2$) , with the exception of FF for which a medium effect sizes (Cohen test, $d = 0.5$ medium) was found between the "Middle Eastern" and "Asian" groups (Field, 2009). Additionally, further research would be needed and should use larger samples for being representative of each culture. However it is worth mentioning that previous studies pointed out that the effect of social-cultural factors has proven to be insignificant for perception of water sounds (Yu and Kang, 2008) (Yu and Kang, 2010) (Galbrun and Ali, 2013). Furthermore, different subjective ratings might be partly attributed to the evocation and meaning that water sounds can have for different cultures, as already stated by Galbrun and Ali (2013).

4.2.2. Visual-only preferences

Results from the visual-only test identified the preferred water features' displays as shown in Figure 4.2. Visual displays were ranked positively for ST, FTW and CA: results are identical to those found for audio-only preferences. The least preferred displays were PEW, SEW and LJT. Additionally, the single upward jets (LJT and LJT) tended not to be liked. No significant correlations were found between visual-only

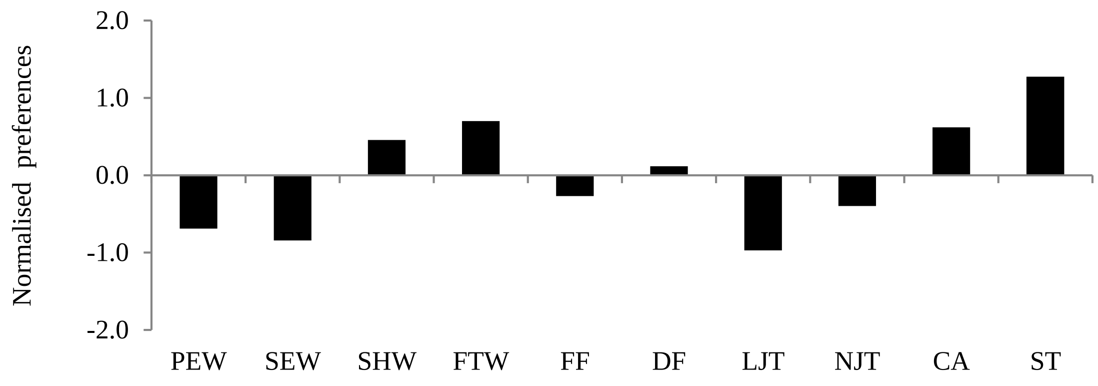


Figure 4.2 Normalised preferences for the visual-only test (refer to Table 3.1 for acronyms and details of water sounds and Figure 3.5 for displays of water features).

preferences and the objectives of water features (Spearman test, $p > 0.05$). Furthermore, no statistically significant differences in responses were found between different ages and genders (Mann-Whitney test, $p > 0.05$), with the exception of FF for responses of different genders (Mann-Whitney test, $p < 0.05$, $p = 0.028$) (the foam fountain (FF) displays was preferred by around 90% of females and only 60% of males). No significant differences in ratings were found between different cultural groups (Kruskal-Wallis, test, $p > 0.05$).

4.2.3. Audio-visual preferences

Preferred water features obtained from the audio-visual test were ST, CA and FTW: these are the water features which made participants feel more relaxed (Figure 4.3). Again these results are very similar to those found for audio-only and visual-only preferences. Furthermore, the least preferred water features were LJT, PEW and NJT. No significant correlations were found between audio-visual preferences and the water features' objective categories (Spearman test, $p > 0.05$). Additionally, no significant differences in responses were found between different ages and genders (Mann-Whitney test, $p > 0.05$) as well as different cultural groups (Kruskal-Wallis test, $p > 0.05$).

4.2.4. Comparing preferences obtained from uni-modal and bi-modal test conditions

Overall, results suggested that the differences in preference scores between uni-modal and bi-modal sensorial conditions vary with different waterscapes (Figure 4.3). In the case of ST , CA and SHW, the effect of visual stimulus on audio-visual preferences was positive: mean preference scores increased as displays of water features were added to

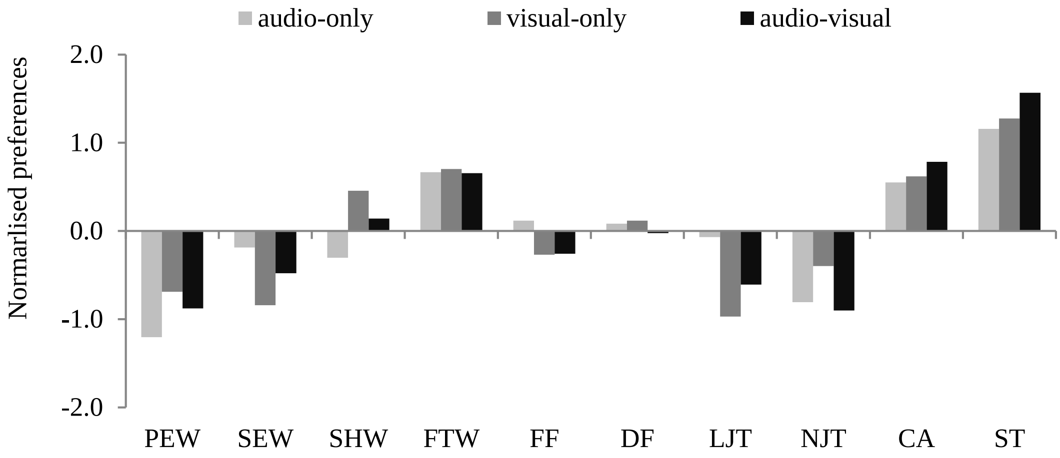


Figure 4.3 Preferred water features for the three tests' conditions (refer to Table 3.1 for acronyms and details of water features).

the corresponding sound stimuli (Table 4.1). Additionally, a lower or equal standard deviation was found between audio-only and audio-visual normalised preferences for ST, SHW and CA, indicating that responses were equal or more polarised (Table 4.1). By contrast, visual stimuli negatively influenced perception in the cases of SEW, FF and LJT and marginally PEW, DF and NJT: mean preference scores decreased with the presentation of the visual displays (Table 4.1). Additionally, the standard deviations of audio-visual preferences were greater than those related to preferences in audio-only conditions for FF and LJT, while greater values were found for SEW, PEW, and DF (e.g. more scattering around the mean value) (Table 4.1). In the case of FTW, mean preferences were equal between audio-only and audio-visual conditions with an increase of the standard deviation for audio-visual preferences (Table 4.1).

Furthermore, independent *t*-tests were carried out in order to evaluate the mean differences in preference scores between uni-modal and bi-modal test conditions. The comparison between audio-only and audio-visual preferences indicated that mean differences in preference scores are significant only for ST [$t(74) = -2.53$, $p < 0.05$], the visual stimulus significantly increasing preference scores (mean normalised preference score of 1.16 (SD = 0.86) and 1.57 (SD = 0.51) for the audio-only and audio-visual tests, respectively). Similarly, the comparison between visual-only and audio-visual preferences showed significant mean differences only for NJT [$t(74) = 2.27$, $p < 0.05$], the auditory stimulus significantly decreasing preference scores (mean normalised

Table 4.1 Mean values and standard deviations (SD) of the normalised preferences obtained from the audio-only, visual-only and audio-visual tests, for ten water features used over road traffic noise (refer to Table 3.1 for definitions and acronyms).

Sound code	Audio-only pref.	Visual-only pref.	Audio-visual pref.
	Mean (SD)	Mean (SD)	Mean (SD)
CA	1.5 (0.7)	1.6 (0.8)	1.7 (0.7)
ST	2.1 (0.8)	2.2 (0.9)	2.5 (0.5)
SEW	0.8 (0.7)	0.1 (1.0)	0.5 (0.8)
SHW	0.7 (1.1)	1.4 (0.8)	1.1 (1.0)
PEW	0.2 (0.1)	0.3 (1.2)	0.1 (1.0)
FF	1.1 (0.9)	0.7 (1.1)	0.7 (0.1)
DF	1.0 (0.6)	1.1 (0.6)	0.9 (0.7)
FTW	1.6 (0.5)	1.6 (0.1)	1.6 (0.8)
LJT	0.9 (1.6)	0.0 (0.9)	0.3 (1.4)
NJT	0.2 (0.9)	0.6 (1.0)	0.1 (0.9)

preference score of -0.40 (SD = 1.02) and -0.90 (SD = 0.91) for the visual-only and audio-visual tests, respectively). The *t*-test results suggested that an added stimulus (either visual or auditory) only rarely leads to a significant change in preferences.

The influence of water features' displays on sound perception is explained further through the analysis carried out for the visual categorisation (manmade vs. natural) of the ten water features used in this study, which is given in Chapter 5 (section 5.4.2).

4.2.5. Discussion

Statistically significant correlations occurred between audio-only preferences and objective categories of water features. These indicated that natural shallow streams tend to be preferred to fountains, which are in turn preferred to waterfalls, confirming findings of previous research (Galbrun and Ali, 2013).

Normalised preferences obtained from the visual-only tests showed identical results to those found in audio-only conditions. ST, CA and FTW tended to be the preferred water features' displays, whilst PEW, SEW and LJT tended to be poorly rated visually. Furthermore, single upward jets (LJT and NJT) tended not to be liked, unlike multiple upward jets that were identified as visually pleasing in previous research (Nasar and Lin, 2003).

The evaluation of audio-visual preferences indicated again very similar results to those found for audio-only and visual-only preferences. ST, CA and FTW tended to be the water features which made participants feel more relaxed in the presence of road traffic noise, whilst LJT, PEW and NJT were the least preferred water features.

Differences in preferences scores between uni-modal and bi-modal sensorial conditions vary with different waterscapes. The addition of a visual stimulus increased preferences in some cases (ST, CA and SHW, three out of the ten water features), but decreased them in other cases (SEW, FF and LJT and (marginally) PEW, DF and NJT, six out of the ten water features). As paired comparisons were used, an increase in preference scores for some features necessarily led to a decrease for other features. Therefore, these results do not mean that some visual stimuli are detrimental. Rating scales used in waterscape studies (Watts *et al.*, 2009; Jeon *et al.*, 2012) showed that the addition of a visual stimulus improves perception most of the time (compared to audio-only perception). However, the improvements in the preference scores were affected by the type of water feature considered (Jeon et al., 2012). This is in line with results pointed out in the study presented here: some water features benefit more than others from a visual stimulus. Furthermore, independent *t*-tests showed significant mean differences in preference scores between audio-only and audio-visual preferences only in one case (ST) out of ten water features. Similarly, the comparison between visual-only and audio-visual preferences indicated significant mean differences only for one case (NJT) out of ten water features. Although preference scores changed when a stimulus was added, mean differences indicated that an added stimulus (either visual or auditory) only rarely leads to a statistically significant change (only one waterscape out of ten). This result suggested that a single stimulus is rarely dominant in driving waterscapes' preferences.

4.3 Correlations between audio-only vs. visual-only vs. audio-visual preferences

In this section, results in terms of correlations between audio-only, visual-only and audio-visual preferences are given for each water feature which has been examined in the study presented here (see Table 4.1 for definition and acronyms of water features).

4.3.1 Results

Statistically significant (positive and high) correlations were found between the average ranking positions of the three tests (Spearman test): $\rho = 0.71$ with $p < 0.05$ for audioonlyvs. visual-only, $\rho = 0.83$ with $p < 0.01$ for audio-only vs. audio-visual, and $\rho = 0.76$ with $p < 0.05$ for visual-only vs. audio-visual.

Additional correlation analysis was carried out using the preference data of all participants rather than averages, and results are presented in Table 4.2. It was found that subjective sound ratings are not correlated with visual ratings, although the significant correlations obtained using averages are important and should not be discarded, as the use of average values decreases the errors within the test. On the other hand, responses from audio-only tests were significantly correlated with the combined audio-visual condition for seven out of ten water features (medium correlation for SHW, low correlations for PEW, FF, DF and FTW, high correlations for LJT and NJT). Similarly, a significant correlation was found between visual-only and audio-visual results again for seven out of ten water features (medium correlations for CA, ST, FF and FTW, while low correlations for SHW, PEW and DF). In other words, subjective preferences in the combined audio-visual condition was found to be related to uni-modal sensorial patterns (audio-only and visual- only). The significant relationship between the audio-only and the bi-modal condition was found for SHW, LJT and NJT at the 0.01 level ($p < 0.01$) and for PEW, FF, DF and FTW at the 0.05 level ($p < 0.05$). Additionally, the significant correlations between audio-visual and visual-only condition were found for CA, ST, FF, and FTW at the 0.01 level ($p < 0.01$) (positive and medium correlations);

Table 4.2 Correlations (correlation coefficient ρ, Spearman test) between audio-only, visual-only and audio-visual preferences, for ten different features used over road traffic noise (refer to Table 3.1 for definitions and acronyms).

Sound code	Audio-only vs. Visual-only	Audio-only vs. Audio-visual	Visual-only vs. Audio-visual
CA	-0.12	0.19	0.53**
ST	-0.02	0.29	0.47**
SEW	-0.32	0.24	0.17
SHW	0.28	0.49**	0.35*
PEW	0.26	0.32*	0.37*
FF	0.00	0.41*	0.52**
DF	0.03	0.37*	0.39*
FTW	0.05	0.33*	0.48**
LJT	-0.05	0.56**	0.03
NJT	0.08	0.63**	0.25

** Significant correlation at the 0.01 level (p < 0.01); *Significant correlation at the 0.05 level (p < 0.05).

whilst significance in correlation was observed for SHW, PEW and DF at the 0.05 level ($p < 0.05$) (positive and low correlations).

Furthermore, correlations occurred between both uni-modal scores and audio-visual scores for five out of ten water (SHW, PEW, FF, DF, FTW), whilst a single stimulus appeared to be dominant in the audio-visual rating only for a minority of water features (visual dominance for CA and ST, and auditory dominance for LJT and NJT), as already pointed out by the *t*-tests results.

The relationship between different sensorial patterns and subjective preference was then examined by looking at the statistical significance of differences between preferences scores. The results obtained from a comparison between the different tests' conditions showed that:

- ✓ *Audio-only vs. Visual-only*: significant differences in responses occurred for SEW, SHW, PEW and LJT (Mann-Whitney test, $p < 0.05$; $p = 0.001$ for SEW and SHW, $p = 0.048$ for PEW, $p = 0.029$ for LJT);
- ✓ *Audio-only vs. Audio-visual*: significant differences occurred just for ST (Mann-Whitney test, $p < 0.05$; $p = 0.022$);
- ✓ *Visual-only vs. Audio-visual*: significant differences occurred for SEW and NJT (Mann-Whitney test, $p < 0.05$; $p = 0.033$ for SEW and $p = 0.018$ for SJT);
- ✓ *Audio-only vs. Visual-only vs. Audio-visual*: significant differences occurred for SEW and SHW (Kruskal-Wallis test, $p < 0.05$; $p = 0.002$ for SEW and $p = 0.005$ for SHW).

Additionally, a multiple linear regression was carried out in order to further explain the contributions of water sounds and visual images on preferences of combined stimuli for the ten water features tested. The analysis was conducted using the preferences in uni-modal sensorial conditions ("$Pref_{audio\text{-}only}$" and "$Pref_{visual\text{-}only}$") as independent variables in view of predicting the audio-visual preferences ("$Pref_{audio\text{-}visual}$") as dependent variable.

$$Pref_{audio-visual} = b_0 + b_{Pref_{audio-only}} Pref_{audio-only} + b_{Pref_{visual-only}} Pref_{visual-only} \tag{4.1}$$

The value of R^2 was equal to 0.54 and the associated *F-ratio* is 224.08, with a statistical significance at the 0.05 level ($p < 0.05$) [$R^2 = 0.16$, $F(2,377) = 224.08$]. Results showed

Table 4.3 Multiple linear regression data for predicting audio-visual preferences in relation to preferences in uni-modal sensorial conditions. The model fitting information.

Predictors	Coefficient ($b; b_0$)	t-test	p value	95% Confidence interval	
				Lower bound	Upper bound
$Pref_{audio\text{-}only}$	0.50	13.20	**0.000****	0.42	0.57
$Pref_{visual\text{-}only}$	0.44	12.20	**0.000****	0.37	0.51
Constant b_0	0.28	1.24	0.21	-0.16	0.70

**Significant correlation at the 0.01 level ($p < 0.01$).

that both audio-only and visual-only are significantly influencing preferences in audio-visual tests conditions (Table 4.3). Predictions of audio-visual preferences can be found as:

$$Pref_{audio-visual} = 0.50 \cdot Pref_{audio-only} + 0.44 \cdot Pref_{visual-only} \tag{4.2}$$

It can also be noted that both preferences in uni-modal sensorial conditions had a positive and similar effect on preferences in audio-visual test conditions.

4.3.2 Discussion

The analysis of correlations (based on Spearman's test) between audio-only vs. visual-only vs. audio-visual preferences for each water feature showed that subjective sound ratings are not correlated with visual ratings for the water features considered in the study presented here. By contrast, it was pointed out that subjective perception in the combined audio-visual condition tends to be influenced by uni-modal sensorial patterns (both audio-only and visual-only). As already indicated by results in terms of mean differences, these results suggested that a single stimulus is rarely dominant in driving waterscapes' perception.

Additionally, the analysis of differences in responses between the three tests' conditions showed that there is no unique dominant pattern of preferences between uni-modal conditions: both audio-only and visual-only settings significantly influence waterscapes' perception.

This is in line with results obtained in the study of Hong and Jeon (2013) on the design of sound and visual components for the enhancement of urban soundscapes. It was demonstrated that both the visual and acoustic perception are significant in improving the overall quality of an environment when road traffic noise is around 55 dBA (Hong and Jeon, 2013). However, it is worth pointing out that the visual components used in that work consisted of natural elements such as green spaces and water features placed over an urban background. In the study presented here, the audio-visual tests were based on visual materials including different water features placed over the same natural green background.

Overall, both auditory and visual stimuli tended to affect preferences. Results showed that auditory and visual stimuli are equally important in the audio-visual assessment of half of the water features tested, with one stimulus being dominant only in a minority of features. Additionally, multiple linear regression showed the positive significant of both auditory and visual stimuli in predicting preferences in combined sensorial conditions. This reflects the interdependence between uni-modal perception and bi-modal perception and suggests that equal attentions should be given to the design of both stimuli.

4.4 Hierarchical cluster analysis of preferences

4.4.1 Results

A concordance analysis was carried out in order to determine the degree of agreement among participants in rating preferences for the three test conditions tested. A low agreement was found for the audio-only, visual-only and audio-visual tests (Kendall's coefficient of concordance $W_{\text{audio-only}} = 0.3$, $W_{\text{visual-only}} = 0.5$, $W_{\text{audio-visual}} = 0.6$, $p < 0.001$). This low agreement between preferences was examined further by conducting a hierarchical cluster analysis in order to discover revealing associations and structures in the observed data.

A hierarchical cluster analysis was used as an explanatory tool for finding relatively homogenous clusters of cases among the preferences scores by all 38 participants obtained for the audio-only (Table 4.4), audio-visual (Table 4.5) and visual-only tests (Table 4.6). This analysis was carried out through a Linkage Method (average linkage) by applying a Square Euclidian distance as the distance or similarity measure in order to discover the optimum number of clusters for the data set used (Field, 2009). A dendrogram (visualization of cluster analysis) was used to identify the memberships for each cluster by displaying the distance level at which there was a combination of similar cases (similar preferences among participants). In the case of audio-only preferences, participants were grouped in two clusters (cluster 1 of 17 participants including 9 males and 8 females with a mean of 30.06 years and standard deviation of 6.12 years; and cluster 2 of 21 participants including 10 males and 10 females with a mean of 30.24 years and standard deviation of 2.64 years). According to results obtained from the qualitative "open-ended" description of water sounds (section 6.4.3, Chapter 6), it can be noted that sounds from the small holes waterfalls (SHW) were evocative of rainfall for 5 out of 17 participants in cluster 1 as well as for 7 out of 21 participants of cluster 2. Additionally, the large jet (LJT) was rated by 6 and 13 participants of cluster 1 and 2 respectively. In particular; 3 participants of cluster 1 rated LJT as a manmade sound (tap water), 1 rainfall and 2 natural sound (stream and fountain sounds); whilst it was associated to manmade sounds (tap water) in 9 cases out of 21 of cluster 2. Sounds from the natural stream (ST) was rated by 2 and 7 participants of cluster 1 and 2 respectively, but it was mainly associated to natural sounds in all cases. Furthermore, a similar trend was found for the cascade with four steps (CA) (rated by 3 and 10 participants of cluster 1 and 2 respectively, and was mainly evocative).

Table 4.4 Ranking of preferences obtained for the audio-only tests from all participants retained for the analysis and from clusters obtained from hierarchical cluster analysis. The preferences are listed as normalised preference values. Kendall’s coefficient of concordance, *W*, is also given for results including all participants and for the clusters.

Ranking	AUDIO-ONLY TEST All participants		Cluster 1(17 part.)		Cluster 2 (21 part.)	
	Sound code	Norm. Pref.	Sound code	Norm. Pref.	Sound code	Norm. Pref.
1	ST	1.16	CA	0.80	ST	1.53
2	FTW	0.67	FTW	0.72	LJT	1.15
3	CA	0.55	ST	0.69	FTW	0.62
4	FF	0.12	SHW	0.69	FF	0.37
5	DF	0.08	DF	0.59	CA	0.35
6	LJT	-0.07	SEW	0.17	DF	-0.33
7	SEW	-0.19	FF	-0.20	NJT	-0.41
8	SHW	-0.30	PEW	-0.59	SEW	-0.48
9	NJT	-0.81	NJT	-1.29	SHW	-1.11
10	PEW	-1.20	LJT	-1.58	PEW	-1.70
W		0.33		0.51		0.66

Table 4.5 Ranking of preferences obtained for the audio-visual tests from all participants retained for the analysis and from clusters obtained from hierarchical cluster analysis. The preferences are listed as normalised preference values. Kendall's coefficient of concordance, *W*, is also given for results including all participants and for the clusters.

Ranking	AUDIO-VISUAL TEST					
	All participants		Cluster 1(11 part.)		Cluster 2 (27 part.)	
	Sound code	Norm. Pref.	Sound code	Norm. Pref.	Sound code	Norm. Pref.
1	ST	1.57	ST	1.56	ST	1.57
2	CA	0.78	LJT	1.23	CA	0.90
3	FTW	0.65	FTW	0.83	SHW	0.60
4	SHW	0.14	CA	0.51	FTW	0.58
5	DF	-0.02	FF	0.06	DF	0.09
6	FF	-0.26	DF	-0.30	SEW	-0.35
7	SEW	-0.48	NJT	-0.30	FF	-0.39
8	LJT	-0.61	SEW	-0.79	PEW	-0.50
9	PEW	-0.88	SHW	-0.99	NJT	-1.14
10	NJT	-0.90	PEW	-1.80	LJT	-1.36
W		0.41		0.71		0.54

The analysis of the audio-visual preferences (Table 4.5) showed that all participants were grouped in two clusters (11 participants for cluster 1 including 6 males and 5 females with a mean of 30.55 years and standard deviation of 2.70 years; and 27 participants for cluster 2 including 13 males and 14 females with a mean of 29.96 years and standard deviation of 5.06 years). Finally, three clusters were found for the visual-only preference scores (Table 4.6): cluster 1 of 31 participants (16 males and 14 females with a mean of 30.26 years and standard deviation of 4.67 years), cluster 2 of 4 participants (2 males and 2 females with a mean of 29.50 years and standard deviation of 4.65 years) and cluster 3 of 3 participants (1 males and 2 females with a mean of 27.33 years and standard deviation of 4.51 years).

The audio-only ranking of preferred water sounds obtained from all participants retained for the analysis and from the two clusters showed no significant variations between ranking positions with the exception of LJT and SHW (Table 4.2). LJT changed from the last position in cluster 1 to the second position in cluster 2 (variation of up to 8 ranking positions between clusters). The position of SHW varied from fourth in cluster 1 to ninth in cluster 2 (± 5 positions). A concordance analysis made for the clusters 1 and 2 showed that the concordance coefficient increased significantly compared to that obtained for audio-only preferences by all 38 participants (Table 4.4).

The hierarchical cluster analysis for the audio-visual preferences showed similar results to those found for the audio-only preferences (Table 4.5), as the features the most affected by clusters were again LJT (± 8 positions) and SHW (±6 positions). Furthermore, low variations between ranking positions were obtained for all remaining sounds (cluster 1 and cluster 2, see Table 4.5 for details).

In the case of visual-only preferences, the water features most affected by clusters were FTW (± 7 positions), NJT (± 4 positions), PEW (± 6 positions), and SEW (± 8 positions). No significant variations were found between the visual ranking of preferred water features for LJT and SHW (Table 4.6). The large jet (LJT) was negatively rated (positions 7-10) whilst the waterfall with small holes (SHW) was positively rated (positions 3-5) for all three clusters. Overall, a high degree of agreement was found between participants included in clusters 2 and 3. Furthermore, it can be noted that consistent visual-only preferences were found between most of the participants (31 out of 38 participants in cluster 1).

Table 4.6 Visual-only ranking of preferred water features obtained from all participants retained for the analysis and from clusters obtained from hierarchical cluster analysis. The preferences are listed as normalised preference values. Kendall's coefficient of concordance, *W*, is also given for results including all participants and for the clusters.

VISUAL-ONLY TEST								
	All participants		Cluster 1 (31 part.)		Cluster 2 (4 part.)		Cluster 3 (3 part.)	
Ranking	Sound code	Norm. Pref.	Sound code	Norm. Pref.	Sound code	Norm. Pref.	Sound code	Norm. Pref.
1	ST	1.27	ST	1.34	ST	1.67	CA	1.70
2	FTW	0.70	FTW	1.01	SEW	1.00	PEW	1.56
3	CA	0.62	CA	0.51	NJT	0.78	SHW	1.11
4	SHW	0.46	SHW	0.42	CA	0.67	ST	0.07
5	DF	0.12	DF	0.19	SHW	0.22	DF	-0.22
6	FF	-0.27	FF	-0.15	DF	-0.22	SEW	-0.37
7	NJT	-0.40	NJT	-0.49	LJT	-0.67	FTW	-0.37
8	PEW	-0.69	PEW	-0.78	FF	-0.89	FF	-0.67
9	SEW	-0.84	LJT	-0.92	FTW	-0.89	NJT	-0.96
10	LJT	-0.97	SEW	-1.13	PEW	-1.67	LJT	-1.85
W		0.35		0.43		0.73		0.82

Overall, results suggested that ranking variations between preferences for all 38 participants and the clusters obtained from the audio-only, visual-only and audio-visual tests are not significant. However, there was a low agreement between participants in judging the water features LJT and SHW, in both audio-only and audio-visual conditions but not in the visual-only condition. This indicated that LJT and SHW were either liked or disliked, and this separated them into two distinct separate groups.

4.4.2 Discussion

The analysis of concordance (*W*, Kendall's coefficient) showed a low agreement between participants in rating preferences for the audio-only, visual-only and audio-visual tests. This low agreement between preferences was explained by conducting a hierarchical cluster analysis. Results showed that audio-only and audio-visual preferences were grouped in two clusters, whilst visual-only preferences were grouped in three clusters. The analysis of concordance made for the clusters obtained in all three tests' conditions showed that the degree of agreement between participants included in each cluster significantly increased in comparison to the one observed from the analysis made for preferences by all 38 participants.

The analysis of audio-only, visual-only as well as audio-visual rankings of preferred water features obtained from all participants retained for the analysis and the clusters obtained for each tests' condition showed no significant variations between ranking positions, with the exception of LJT and SHW. It was found that there was a low agreement among participants in judging the large jet (LJT) as well as the waterfall with an edge made with small holes (SHW) in both the audio-only and audio-visual conditions, but not in the visual-only condition.

Overall, results suggested that some water features can be either liked or disliked by different participants, although this tends to be unusual (observed only for two features out of ten).

4.5 Correlations between preferences and acoustic/psychoacoustic parameters

4.5.1 Results

An analysis of correlations between audio-only preferences and the acoustic/psychoacoustic parameters calculated from sounds including both water sounds and road traffic noise was carried out in view of understanding the effect of physical properties of sounds on preferences (Table 4.7). Results showed no noticeable correlations for individual water sounds between audio-only rankings based on preferences by all participants retained for the analysis and the corresponding acoustic/psychoacoustic parameters (Table 4.5(a)). Preferences from all participants tended to be related to higher temporal variation (positive ρ), as well as lower sharpness (negative ρ).

On the contrary, significant (positive and high) correlations were found between pitch strength ($\rho = 0.64$, $p < 0.05$) and audio-only preferences for cluster 1 (Table 4.7(b)). In the case of cluster 2, audio-only preferences of individual water sounds were significantly correlated to temporal variation in level (L_{A10}-L_{A90}) ($p < 0.05$) and roughness ($p < 0.01$) (positive and high correlations) (Table 4.7(c)).

Overall, the analysis of correlations between preferences of water sounds combined with road traffic noise and their corresponding acoustic/psychoacoustic parameters does not show a clear relationship.

This analysis was also repeated excluding LJT and SHW from the water sounds' list, as it was previously shown that these water sounds show large variations in preference (i.e. they are either liked or not liked). Results obtained excluding LJT showed no significant correlations between rankings based on audio-only preferences of individual water sounds and the corresponding acoustic/psychoacoustic parameters. A similar trend was observed for the analysis carried out excluding SHW as well as both LJT and SHW, as no correlation was found.

4.5.2 Discussion

In order to reveal the effect of physical properties on sound perception, an analysis of correlations between rankings based on water sounds' preferences and the corresponding acoustic/psychoacoustic parameters was carried out. It was found that there is no clear relationship between audio-only rankings of individual water sounds and acoustic/psychoacoustic parameters.

Additionally, results obtained from the analysis carried out by excluding LJT or/and SHW from the water sounds' list showed that rankings of individual water sounds are not correlated to acoustic/psychoacoustic parameters. Overall, this additional analysis did not provide further explanations in finding a unique relationship between acoustic/psychoacoustic parameters and audio-only preferences.

Table 4.7 Audio-only ranking of individual water sounds, together with the corresponding acoustic and psychoacoustic parameters calculated from sounds including water sounds combined with RTN for: (a) all participants retained for the analysis, (b) cluster 1 and (c) cluster 2. Correlation coefficients (Spearman coefficient, ρ) are also given.

Ranking	Sound code	Norm. Pref.	L_{A10}-L_{A90} (dB)	L_{Ceq}-L_{Aeq} (dB)	Sharpness (acum)	Roughness (asper)	Pitch strength
(a) All participants							
1	ST	1.16	1.70	2.5	1.61	0.21	0.08
2	FTW	0.67	1.50	2.7	1.67	0.08	0.08
3	CA	0.55	1.40	2.7	1.71	0.09	0.08
4	FF	0.12	1.60	2.8	1.61	0.09	0.07
5	DF	0.08	1.40	2.5	1.70	0.05	0.08
6	LJT	-0.07	2.10	2.9	1.42	0.19	0.07
7	SEW	-0.19	1.60	2.7	1.59	0.05	0.07
8	SHW	-0.30	1.40	2.5	1.71	0.04	0.08
9	NJT	-0.81	1.60	2.5	1.67	0.16	0.08
10	PEW	-1.20	1.40	2.8	1.70	0.04	0.07
Spearman's ρ		1.00	0.23	-0.07	-0.15	0.51	0.35
(b) Cluster 1							
1	CA	0.80	1.4	2.7	1.71	0.09	0.08
2	FTW	0.72	1.5	2.7	1.67	0.08	0.08
3	ST	0.69	1.7	2.5	1.61	0.21	0.08
4	SHW	0.69	1.4	2.5	1.71	0.04	0.08
5	DF	0.59	1.4	2.5	1.70	0.05	0.08
6	SEW	0.17	1.6	2.7	1.59	0.05	0.07
7	FF	-0.20	1.6	2.8	1.61	0.09	0.07
8	PEW	-0.59	1.4	2.8	1.70	0.04	0.07
9	NJT	-1.29	1.6	2.5	1.67	0.16	0.08
10	LJT	-1.58	2.1	2.9	1.42	0.19	0.07
Spearman's ρ		1.00	-0.46	-0.40	0.52	-0.15	0.64*
(c) Cluster 2							
1	ST	1.53	1.7	2.5	1.61	0.21	0.08
2	LJT	1.15	2.1	2.9	1.42	0.19	0.07
3	FTW	0.62	1.5	2.7	1.67	0.08	0.08
4	FF	0.37	1.6	2.8	1.61	0.09	0.07
5	CA	0.35	1.4	2.7	1.71	0.09	0.08
6	DF	-0.33	1.4	2.5	1.70	0.05	0.08
7	NJT	-0.41	1.6	2.5	1.67	0.16	0.08
8	SEW	-0.48	1.6	2.7	1.59	0.05	0.07
9	SHW	-1.11	1.4	2.5	1.71	0.04	0.08
10	PEW	-1.70	1.4	2.8	1.70	0.04	0.07
Spearman's ρ		1.00	0.64*	0.10	-0.50	0.82**	0.14

*Significant correlation at the 0.05 level; ** Significant correlation at the 0.01 level.

Previous research by Galbrun and Ali (2013) suggested that no acoustic and psychoacoustic parameter correlated well with individual sound preferences, but analysis made on ranked groups indicated that low sharpness and large temporal variation in level (L_{A10}-L_{A90}) were preferred on average. Overall, the results obtained from the research presented here showed the complexity of finding an interaction between acoustic/psychoacoustic parameters and sound perception of water features, confirming findings of previous work (Galbrun and Ali, 2013).

It is also worth pointing out that all waterscapes analysed in the work presented here consisted of water features with water as the main impact material. It should be noted that water sounds with hard impact materials have higher sharpness than sounds originated from water falling over water, as demonstrated by Galbrun and Ali (2013). By excluding hard impact sounds from the analysis presented here, sharpness variations between water sounds become less marked. The previous tests carried out by Galbrun and Ali (2013) suggested that lower sharpness correlates with relaxation, but results obtained here suggested that this might have been linked with the hard impact water sounds that tend not to be liked.

Furthermore, Watts *et al.* (2009) showed that sharpness represents an important parameter to be considered in rating tranquillity: water sounds with higher sharpness tended to be preferred in terms of tranquillity. In relation to this finding, it is important to note that in the current study the water features considered include upward and downwards water features with water as the main impact material, whilst Watts *et al.* (2009) studied only downwards water features with variable impact materials. Watts *et al.* (2009)' findings might be due to the fact that a downward stream with lower sharpness tends to be associated with man-made sounds such as water falling into a drain or container, and these tend not to be liked (Watts *et al.*, 2009). In this regard, Galbrun and Ali (2013) suggested that sharpness might not be a key factor for driving preferences of all type of water features. According to this finding, adding water features with hard impact materials to this analysis might lead to the same results obtained by Galbrun and Ali (2013).

Overall, current and previous (Galbrun and Ali, 2013) results suggest that there is a weak association between acoustic/psychoacoustic parameters and preferences of water sounds.

4.6 Conclusions

This chapter examined the audio-visual interaction of water features used over road traffic noise in the context of peacefulness and relaxation. Ten small to medium sized water features (streams, fountains and waterfalls) were included in the study presented here.

Results in terms of normalised preferences showed that the natural shallow stream (ST), the cascade with four steps (CA) and the fountain with multi-upward jets (FTW) tend to be preferred in both uni-modal and bi-modal sensorial conditions. A significant correlation was found between audio-only preferences and the water features' objective categories. This result pointed out that natural shallow stream sounds tend to be preferred over fountains sounds, which are in turn preferred over waterfalls sounds, confirming the findings illustrated by Galbrun and Ali (2013).

Results also confirmed that the audio-visual interaction plays an important role on subjective perception. The impact of water features' displays on the preferences of the corresponding sound stimuli depends mainly on the type of water features considered, as illustrated in previous research (Watts *et al.*, 2009; Jeon *et al.*, 2012). In four cases out of the ten water features considered, visual stimuli had a positive effect on sound perception by increasing the preference scores in audio-visual conditions. On the contrary, the visual effect was negative on sound perception for six cases out of the ten water features. These results did not mean that some visual stimuli are detrimental, but simply that some features benefit more than others from a visual stimulus (one case out of ten). A further discussion on the visual categorisation of water features is given in Chapter 5.

Furthermore, significant mean differences in preference scores were found between audio-only and audio-visual preferences only in one case out of ten water features. A similar trend was found for the comparison between visual-only and audio-visual preferences (significant mean differences only for 1 case out of 10). Although preference scores changed when a stimulus was added, mean differences indicated that an added stimulus (either visual or auditory) only rarely leads to a statistically significant change. This result suggested that a single stimulus is rarely dominant in driving waterscapes' preferences.

Statistically, no correlation was found between preferences scores in audio-only and visual-only conditions. However, the subjective perception in the combined audio-visual condition was significantly influenced by the uni-modal sensorial patterns (both audio-only and visual-only conditions). These results confirmed furthermore that a single stimulus is rarely dominant in driving waterscapes' perception.

Furthermore, the analysis of differences in responses between the three tests' conditions pointed out that there is no unique dominant pattern of preferences between audio-only and visual-only conditions, as auditory and visual stimuli are equally important in the audio-visual assessment of water features.

Overall, results suggested that both auditory and visual stimuli tend to affect preferences. This reflected the interdependence between uni-modal and bi-modal perception suggesting that equal attention should be given to the design of both stimuli.

Additional analysis showed no differences in responses between different age and gender for the three test conditions (with the exception of different responses between different genders for FF in the visual-only condition). On the contrary, differences in responses were found among different cultural groups in the case of waterfalls and fountains for the audio-only test. However, the small sample sizes of cultural groups suggest that these findings might not be relevant, especially considering that previous research (Yu and Kang, 2010) (Galbrun and Ali, 2013) pointed out that socio-cultural factors have no influence on waterscapes' perception.

Results from a hierarchical cluster analysis showed that no significant variations in preferences were observed between ratings in uni-modal and bi-modal sensorial conditions. However, LJT and SHW were found to be liked or disliked due to a low agreement among participants in judging these water features in both audio-only and audio-visual conditions. Overall, results suggested that some water features can be either liked or disliked by different participants, although this tends to be unusual (observed only for two features out of ten).

Finally, no clear correlations were found between perception of water sounds and acoustic/psychoacoustic parameters of the corresponding stimuli, as suggested by previous studies (Galbrun and Ali, 2013). There is a complexity in finding an interaction between physical properties of sounds and subjective perception. Results showed that no individual physical parameters might be considered as key factors in rating relaxation and peacefulness, as already pointed out by Galbrun and Ali (2013). Factors such as the type of water features (streams vs. fountain vs. waterfalls), the impact material (water vs. hard material) and the emotional attributes related to water sounds (discussed in Chapter 5) might be more influential factors affecting subjective perception.

CHAPTER 5

Semantic Analysis of Water Sounds used over Road Traffic Noise[1]

5.1 Introduction

This chapter focuses on the qualitative analysis of different water sounds used over road traffic noise with the objectives of identifying the principal semantic components affecting the perception of water sounds, and investigating the relationship between semantic components and acoustic/psychoacoustic parameters as well as preferences of their corresponding water sounds (objectives 3 and 4, as shown in section 1.3 of Chapter 1). The assessment of preferences obtained from the semantic differential test is firstly illustrated, in view of identifying a qualitative characterisation of the ten waterscapes used in this study. A principal component analysis was then examined to define the principal components affecting perception of water sounds. In addition, the logit regression models for both audio-only and audio-visual preferences in relation to the principal semantic components are given. The analysis of rankings based on the semantic component/attributes scores in relation to the preferred and least liked water features in the audio-only tests aimed at understanding the relationship between the semantic characterisation and preferences of water sounds. Furthermore, the correlations between semantic components/attributes and sound preferences were also evaluated in order to examine the impact of water sounds' characterisation on subjective perception. The analysis of correlations between semantic components/attributes and acoustic/psychoacoustic parameters is then described in view of revealing a connection between physical sound properties and water sounds' characterisation. Finally, a critical discussion is given at the end of the chapter.

5.2 Semantic analysis

A semantic differential test was carried out in view of evaluating the qualitative characterisation of the ten different waterscapes used in the study presented here. The semantic differential method was used to characterise each water sound based on adjective scales which represent specific connotative meanings of these sounds. This

[1]Some sections of this chapter are based on the paper: L. Galbrun and F.M.A. Calarco, "Audio-visual interaction and perceptual assessment of water features used over road traffic noise", *J. Acoust. Soc. Am.*, **136(5)**, 2609–2620, (2014).

technique was identified as the most suitable method which allows connecting a subject's feeling at both linguistic and psychological levels with sound sources (Kang, 2007). This test was carried for the ten water sound tested in audio-visual tests (Table 3.1) by using a five-point verbal scale based on nine semantic attributes. Based on a review of previous works, the qualitative semantic attributes were selected for the charactersiation of water sounds: relaxation (relaxing-stressful), naturalness (natural–artificial), familiarity (familiar–unfamiliar), freshness (refreshing–weary), perceived sharpness (sharp–flat), perceived roughness (rough–smooth), speed (fast-low), envelopment (enveloping-directional) and temporal variation (unsteady-steady) (more details can be found in section 3.4.1 of Chapter 3).

5.2.1 Results and correlations between semantic attributes

Thirty-eight subjects (nineteen females and nineteen males) passed the consistency test (judgements within a 95% confidence interval) and were retained for the analysis of results. The age distribution of subjects ranged from 24 to 47 years (mean 30.5 years and standard deviation 4.47 years). The cultural groups were composed of nineteen "White", four "Asian", fourteen "Middle Eastern" and one "African" (as shown in Chapter 4).

Results have been expressed as average scores based on a five-point numerical scale (e.g. -2 = very stressful, -1 = stressful, 0 = neither stressful nor relaxing, 1 = relaxing, 2 = very relaxing) for each pair of antonymous adjective (9 adjectives: relaxing-stressful; natural-artificial; refreshing-weary; familiar-unfamiliar; sharp-flat; rough-smooth; fast-slow; enveloping-directional; unsteady-steady).

The average scores obtained for each attribute are given in Table 5.1. Each attribute corresponds to a colour code where red colour indicates ratings between -2 and 0 for each semantic attribute, whilst ratings between 0 to +2 were assigned the colour blue. In addition, trends of semantic attributes for each water feature considered in this study can be visualised in Figure 5.1 (page 149) which also includes the principal components affecting the perception of water sounds. This is discussed in detail in section 5.3.2.

For the attribute relaxation, the natural shallow stream (ST), the fountain with 37 upward jets (FTW) and the cascade with four steps (CA) were rated as the most relaxing sounds. These sounds were also defined as the most natural and refreshing, as well as familiar sounds. Sounds such as NJT and PEW were associated to high values of perceived sharpness and perceived roughness. ST and CA, which were preferred sounds

Table 5.1 Average scores for each semantic attribute where dark colours corresponds to higher values, with sound codes listed in order of preference ratings obtained from the audio-only test based on a 5-point numerical scale (e.g. -2 = very stressful, -1 = stressful, 0 = neither stressful nor relaxing, 1 = relaxing, 2 = very relaxing).

Aural ranking	Sound code	Relaxation	Naturalness	Freshness	Familiarity	Perceived sharpness	Perceived roughness	Speed	Envelopment	Temporal variation
1	ST	1.39	1.45	1.16	1.18	-0.55	-1.05	-0.18	0.18	-0.50
2	FTW	0.89	0.82	0.74	1.00	-0.11	-0.37	0.13	0.13	-0.32
3	CA	0.68	0.92	0.55	1.13	-0.47	-0.53	0.47	0.58	-0.47
4	FF	0.13	-0.03	0.26	0.50	-0.11	0.13	0.16	-0.34	0.45
5	DF	0.32	0.76	0.16	0.89	-0.08	-0.11	0.61	0.50	-0.29
6	LJT	0.26	-0.34	-0.13	0.79	-0.08	-0.08	-0.21	-0.50	0.24
7	SEW	0.34	0.55	0.24	0.74	-0.08	0.03	0.42	0.26	-0.21
8	SHW	0.21	0.76	0.32	1.03	-0.13	-0.21	0.84	0.79	-0.76
9	NJT	0.34	-0.39	-0.29	0.55	0.29	0.50	0.39	-0.79	0.55
10	PEW	-0.18	0.50	-0.21	0.68	0.18	0.50	1.03	0.87	-0.68

[1.61,2.0]
[1.21,1.6]
[0.81,1.2]
[0.41,0.8]
[0.11,0.4]
[-0.10,0.10]
[-0.11,-0.4]
[-0.41,-0.8]
[-0.81,-1.2]
[-1.21,-1.6]
[-1.61,-2.0]

in both audio-only and audio-visual tests, were assigned low perceived sharpness. The fastest sounds were associated to the plain edge waterfall (PEW) and to the waterfall with small holes (SHW), whilst the slowest sounds were associated to the large jet (LJT) and the natural shallow stream (ST). The waterfalls with a plain edge (PEW) and small holes (SHW), as well as the cascade with four steps (CA), were defined as the most enveloping sounds. Finally, the narrow jet (NJT), the foam fountain (FF) and the large jet (LJT) were classified as the most unsteady sounds (i.e. larger temporal variation).

Overall, positive values tended to be obtained for relaxation, naturalness, freshness and familiarity, whilst results were more scattered between negative and positive values for the attributes of components 2 and 3 (as shown in Figure 5.1). This was analysed in more detail by looking at correlations (Spearman test) between the average scores of the attributes (Table 5.2). Results showed that relaxation, naturalness, freshness, and familiarity are positively and strongly correlated with each other ($p < 0.01$, except for the correlation between freshness and familiarity where $p < 0.05$). This suggested that these attributes provide a mutually positive contribution to each other. For example, the perception of water sounds related to relaxation increased as water sounds were highly rated for naturalness, and vice-versa. A significant correlations was also found between the perceived sharpness and the perceived roughness ($p < 0.01$), and these attributes also showed significant negative and high correlations with relaxation, naturalness, freshness and familiarity ($p < 0.01$, except for the correlations between the perceived sharpness and relaxation where $p < 0.05$). This indicated that high values of perceived sharpness or perceived roughness were associated to low ratings of relaxation, naturalness, freshness and familiarity. Furthermore, envelopment was positively and strongly correlated with speed ($p < 0.01$) and negatively correlated with temporal variation ($p < 0.01$). This suggested that water sounds perceived as more enveloping tend to have a higher flow rate and were steadier.

A statistical analysis of the results showed no significant differences in responses between different ages and genders (Mann-Whitney test, $p > 0.05$) and cultural groups (Kruskal-Wallis test, $p > 0.05$), with only few exceptions observed in the semantic evaluation of freshness and familiarity for different genders and relaxation for different ages, as well as in the evaluation of physical attributes (temporal variation, envelopment, sharpness and speed) for different cultural groups.

Table 5.2 Correlations (correlation coefficients, ρ, Spearman test) between semantic attributes.

	Relaxation	Naturalness	Freshness	Familiarity	Perceived Sharpness	Perceived Roughness	Speed	Envelopment	Temporal variation
Relaxation	1.00	**0.84****	**0.81****	**0.78****	**-0.69***	**-0.87****	-0.38	0.09	-0.30
Naturalness	**0.84****	1.00	**0.86****	**0.88****	**-0.80****	**-0.89****	0.05	0.48	**-0.67***
Freshness	**0.81****	**0.86****	1.00	**0.74***	**-0.93****	**-0.87****	-0.27	0.16	-0.45
Familiarity	**0.78****	**0.88****	**0.74***	1.00	**-0.77****	**-0.94****	-0.06	0.37	**-0.66***
Perceived Sharpness	**-0.69***	**-0.80****	**-0.93****	**-0.77****	1.00	**0.87****	0.20	-0.22	0.48
Perceived Roughness	**-0.87****	**-0.89****	**-0.87****	**-0.94****	**0.87****	1.00	0.25	-0.19	0.49
Speed	-0.38	0.05	-0.27	-0.06	0.20	0.25	1.00	**0.81****	-0.49
Envelopment	0.09	0.48	0.16	0.37	-0.22	-0.19	**0.81****	1.00	**-0.84****
Temporal Variation	-0.30	**-0.67***	-0.45	**-0.66***	0.48	0.49	-0.49	**-0.84****	1.00

*Significant correlation at the 0.05 level; ** Significant correlation at the 0.01 level.

5.2.2 Principal component analysis

A principal component analysis (PCA) was carried out in view of identifying whether it was possible to group the nine semantic attributes into a lower number of components. The PCA was based on the varimax rotation method to extract the orthogonal components, and the criterion of eigenvalues greater than 1 was applied (for more details refer to section 3.4.1 of Chapter 3). Results showed that three main components are important in the characterisation of different waterscapes, as shown in Table 5.3 and Figure 5.1.

The first component included qualitative properties of water sounds. The second and third components were related to psychoacoustical and physical properties of sounds. Different trends for attributes associated to each principal component can be observed in Figure 5.1. Overall, positive values tended to be obtained for relaxation, naturalness, freshness and familiarity, whilst results were more scattered between negative and positive values for the attributes of components 2 and 3. Component 1, called “emotional assessment”, included attributes such as relaxation (relaxing-stressful), naturalness (natural-artificial), freshness (refreshing-weary), and familiarity (familiar- unfamiliar) (Table 5.3). Component 2, called “sound quality”, consisted of perceived sharpness (sharp-flat), perceived roughness (rough-smooth) and speed (fast-slow). Component 3, called “envelopment and temporal variation”, included envelopment

Table 5.3 Principal components and attributes affecting sound characterisation.

COMPONENT	Variance	Attribute	Adjectives
Component 1	32%	relaxation	relaxing-stressful
“Emotional Assessment”		naturalness	natural-artificial
		freshness	refreshing-weary
		familiarity	familiar-unfamiliar
Component 2	20%	perceived sharpness	sharp-flat
“Sound Quality”		perceived roughness	rough-smooth
		speed	fast-slow
Component 3	14%	envelopment	enveloping-directional
“Envelopment and Temporal variation”		temporal variation	unsteady-steady

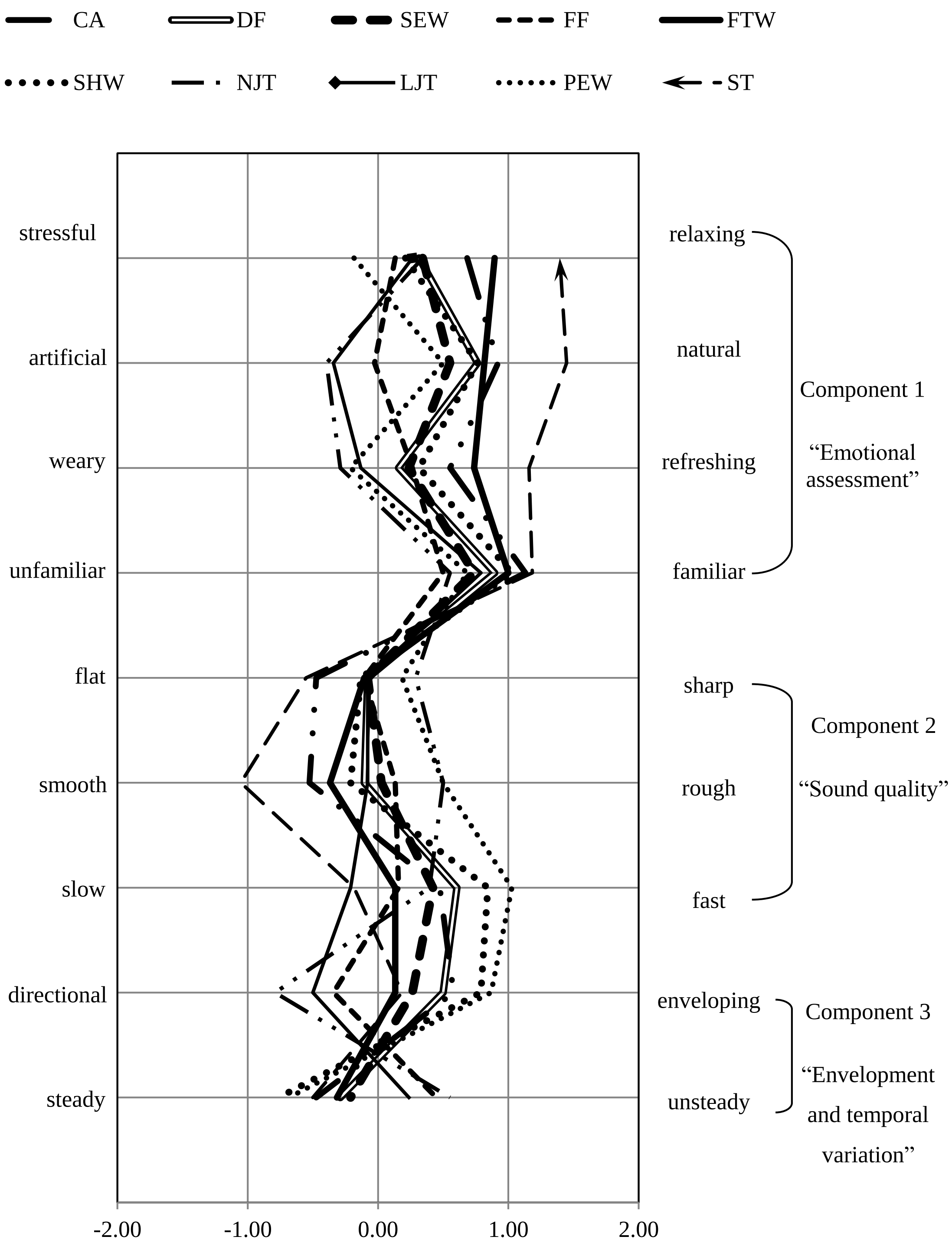


Figure 5.1 Semantic characterisation of the individual water sounds showing principal components and the corresponding attributes.

(enveloping-directional) and temporal variation (unsteady-steady). Component 1 explained 32% of the total variance, followed by component 2 with 20% and component 3 with 14 %, so that emotional attributes explains greater variance rather than physical properties of sounds. Although results showed a medium value as total of explained variance for the three components, this is in line with those found in previous research related to the assessment of soundscape perception by using a semantic differential method (53% total of explained variance for 4 components (Kang and Zhang, 2010); 65 % total of explained variance for 4 components (Davies et al., 2014); 67 % total of explained variance for 4 components (Hong and Jeon, 2015) (refer to Table 2.4-5 of Chapter 2 for details).

Overall, results suggest that the subjective perception of waterscapes depended mainly on the emotional attributes (component 1) associated to each stimulus. However, it was also affected, but in a less significant way, by attributes related to sound quality.

5.2.3 Variations in ranking between semantic component/attributes and audio-only preferences

The variations between ranking positions based on average scores obtained from the semantic differential tests, as well as the normalised preferences for the audio-only test, are shown in Tables 5.4 and 5.5.

Table 5.4 shows that the preferred water features (ST, FTW and CA) in audio-only tests were rated by all subjects on the top of component 1, "emotional assessment". On the contrary, ST and CA were rated negatively for 'sound quality' as well as "envelopment and temporal variation". However, a negative value in "sound quality" should be considered good: sounds (ST, CA and FTW) associated to lower values of component 2 were highly rated in audio-only tests. On the contrary, the ranking positions on the top of "sound quality" were obtained for the water features which tended to be less preferred in the audio-only tests. In fact, the negative sign observed in correlations of "sound quality" is due to the scales used for the perceived sharpness, the perceived roughness and speed, where negative signs actually correspond to preferred sounds (this is explained in more detail in section 5.3.4). The same trend was observed in the case of "envelopment and temporal variation". In addition, it was found that the water sounds CA and ST were poorly rated for component 3, but these corresponded to preferred sounds in the audio-only test. On the contrary, the fountain with 37 upward jets (FTW), which was defined as one of the preferred features, was rated positively for component 3. Table 5.5 shows the ranking positions for each semantic attribute based on the corresponding component, as well as ranking positions from the audio-only tests. The light grey colour was assigned to the preferred water features in audio-only tests; conversely, the water features poorly rated were highlighted with a dark grey colour in the table. These

Table 5.4 Ranking of different water sounds based on the average scores of semantic components, and ranking based on normalised preferences obtained from the audio-only tests.

Semantic component score (Average score)						Preferences (Normalised preference)	
Component 1		Component 2		Component 3		Audio-only	
ST	1,30	PEW	0,52	FTW	0,24	ST	1.16
FTW	0,86	NJT	0,39	NJT	0,11	FTW	0.67
CA	0,82	SHW	0,17	LJT	0,05	CA	0.55
SHW	0,58	DF	0,14	DF	0,05	FF	0.12
DF	0,53	SEW	0,12	FF	0,03	DF	0.08
SEW	0,47	FF	0,06	SHW	0,01	LJT	-0.07
FF	0,22	FTW	-0,11	PEW	-0,09	SEW	-0.19
LJT	0,14	LJT	-0,12	SEW	-0,12	SHW	-0.30
NJT	-0,12	CA	-0,18	ST	-0,13	NJT	-0.81
PEW	-0,14	ST	-0,60	CA	-0,16	PEW	-1.20

colours were used in order to easily identify the ranking positions for each semantic component in relation to the preferred and least liked water features in the audio-only tests.

The highly rated water sounds (ST, CA and FTW) in audio-only conditions were found to be characterised by emotional attributes and defined by the words relaxation, naturalness, familiarity and freshness (Table 5.5(a)).This result suggested that sound proprieties related to emotional assessment might be used together for improving waterscape perception in the context of peacefulness.

The natural shallow stream (ST), defined by the words low perceived sharpness, low perceived roughness and low speed, was the preferred water feature in the audio-only tests (Table 5.5 (b)). A similar trend was observed for the cascade with four steps (CA), with only one difference in the classification for the semantic attribute speed (CA was defined as a fast sound, unlike ST). On the contrary, water sounds defined by the adjectives sharp and rough (NJT and PEW) as well as fast (PEW) were found to be the least liked in audio-only tests (Table 5.5 (b)). Overall, these results suggested that water sounds perceived as having lower sharpness, lower roughness and lower speed tend to be preferred for improving relaxation and peacefulness in the presence of road traffic noise. It should also be noted that results obtained for component 2 (Table 5.5(b))

Table 5.5 Ranking and scores of different water sounds based on the attributes listed under components 1, 2 and 3, and preference scores obtained from the audio-only tests (light grey colour is for the preferred water features, whilst dark grey colour is for the least liked water features in audio-only tests).

(a)

(Average score)

Component 1 – "Emotional assessment"

Relaxation		Naturalness		Freshness		Familiarity		Audio-only Preferences (Norm. pref.)	
ST	1,39	ST	1,45	ST	1,16	ST	1,18	ST	1.16
FTW	0,89	CA	0,92	FTW	0,74	CA	1,13	FTW	0.67
CA	0,68	FTW	0,82	CA	0,55	SHW	1,03	CA	0.55
SEW	0,34	DF	0,76	SHW	0,32	FTW	1,00	FF	0.12
DF	0,32	SHW	0,76	FF	0,26	DF	0,89	DF	0.08
LJT	0,26	SEW	0,55	SEW	0,24	LJT	0,79	LJT	-0.07
SHW	0,21	PEW	0,50	DF	0,16	SEW	0,74	SEW	-0.19
FF	0,13	FF	-0,03	LJT	-0,13	PEW	0,68	SHW	-0.30
PEW	-0,18	LJT	-0,34	PEW	-0,21	NJT	0,55	NJT	-0.81
NJT	-0,34	NJT	-0,39	NJT	-0,29	FF	0,50	PEW	-1.20

(b)

Component 2 – "Sound quality"

Perceived sharpness		Perceived roughness		Speed			
NJT	0,29	NJT	1,45	PEW	1,03	ST	1.16
PEW	0,18	PEW	0,92	SHW	0,84	FTW	0.67
LJT	-0,08	FF	0,82	DF	0,61	CA	0.55
DF	-0,08	SEW	0,76	CA	0,47	FF	0.12
SEW	-0,08	LJT	0,76	SEW	0,42	DF	0.08
FTW	-0,11	DF	0,55	NJT	0,39	LJT	-0.07
FF	-0,11	SHW	0,50	FF	0,16	SEW	-0.19
SHW	-0,13	FTW	-0,03	FTW	0,13	SHW	-0.30
CA	-0,47	CA	-0,34	ST	-0,18	NJT	-0.81
ST	-0,55	ST	-0,39	LJT	-0,21	PEW	-1.20

(c)

Component 3 – "Envelopment and temporal variation"

Temporal variation		Envelopment			
NJT	0,55	SHW	0,79	ST	1.16
FF	0,45	PEW	0,68	FTW	0.67
LJT	0,24	CA	0,58	CA	0.55
SEW	-0,21	DF	0,50	FF	0.12
DF	-0,29	SEW	0,26	DF	0.08
FTW	-0,32	ST	0,18	LJT	-0.07
CA	-0,47	FTW	0,13	SEW	-0.19
ST	-0,50	FF	-0,34	SHW	-0.30
PEW	-0,68	LJT	-0,50	NJT	-0.81
SHW	-0,76	NJT	-0,79	PEW	-1.20

suggested that people are not able to make correct judgments related to sound quality. In fact, the perceived sharpness and the perceived roughness did not always correspond to the equivalent values of sharpness and roughness calculated for the water sounds considered (see Table 4.1 for details). Among all water features studied in this work, the waterfall with small holes (SHW), the fountain with 37 upward jets (FTW) and the cascade (CA) have larger sharpness. But, it can be noted that CA and SHW were rated as having low perceived sharpness. The same trend was observed for sounds (ST and LJT) with larger roughness. On the other hand, a good agreement was found between the low perceived sharpness expressed for the natural shallow stream (ST) and its actual value of sharpness. However, it is worth noting that although ranges of calculated sharpness as well as roughness among the different water sounds tested were limited (1.73-2.2 acum for sharpness and 0.03-0.29 asper for roughness), differences between water sounds were expected to be noticeable in terms of sharpness and roughness and therefore reflected in variations in perceived sharpness and perceived roughness.

Water sounds generated from the large jet fountain (LJT) and the narrow jet fountain (NJT) were defined as directional (i.e. not enveloping) sounds, and tended not to be preferred in audio-only tests condition (Table 5.5(c)).

Finally, it is interesting to note that the natural shallow stream (ST) was not highly rated for the attribute envelopment: this sound was judged as not very enveloping. This result was not expected due to the strong spatial quality reflected in the left and right channels of the binaural recording of the natural stream (this sound was measured at the junction of two streams). This might be due to the fact that people rated envelopment as a quality for which no direction can be associated to the sounds (i.e., not even a combination of right and left channels, as in the case of ST).

5.2.4 Correlations between semantic components/attributes and audio-only preferences

Table 5.6 shows the correlations (Spearman test) between semantic attributes and audio-only preferences for each water feature considered in the study presented here. Relaxation is correlated to the audio-only preferences for the narrow jet NJT) ($p < 0.05$) and the large jet (LJT) ($p < 0.01$) (negative and low correlations in both cases). The same trend was observed for the attribute naturalness in the case of NJT and LJT. Similarly, a significant negative correlation was found between freshness and audio-only preferences for SHW, NJT ($p < 0.05$) (low correlations) and LJT ($p < 0.01$) (high correlations). A negative and weak relationship was also identified with familiarity for SEW and PEW ($p < 0.05$). The perceived sharpness correlated with audio-only preferences for NJT ($p < 0.05$, positive and low correlation): a positive value in perceived sharpness was related to a low rating in the audio-only test. Similarly, perceived roughness was also significantly correlated to the audio-only ratings for NJT ($p < 0.05$, positive and low correlation) and LJT ($p < 0.01$, positive and medium correlation). A positive relationship with speed was also found for NJT and ST ($p < 0.05$, correlation), whilst a negative relationship was found between envelopment and the audio-only preferences for FTW and NJT ($p < 0.05$, low correlation), and a similar trend was observed for temporal variation in the case of CA ($p < 0.05$, negative and low correlation). The narrow jet (NJT) was the only water feature which correlated with seven attributes out of ten, whilst a significant relationship was observed with just one semantic attribute in the case of CA, FTW and ST. In addition, no correlations with semantic attributes were found for DF and FF. Overall, it can be observed that not all water features considered correlated with individual semantic attributes.

The analysis of correlations between results obtained from the semantic components/attributes and subjective preferences from the audio-only tests is shown in Table 5.7. Component 1 ("emotional assessment") was significantly correlated with preference scores from audio-only tests ($p < 0.01$, positive and high correlation), and had a positive relationship with preference scores. This suggested that "emotional assessment" (and in particular, relaxation, naturalness and freshness) can strongly affect subjective perception by increasing preference scores. On the contrary, the correlation between component 2 ("sound quality") and audio-only ratings was found to be significant ($p < 0.01$, negative and high correlation), but high values of 'sound quality' negatively affected preferences. Significant negative correlations with preferences were found in particular for perceived sharpness ($p < 0.05$, negative and high correlation) and perceived roughness ($p < 0.01$, negative and high correlation). In addition, no correlation was found between component 3 and preference scores. The negative relationship found for component 2 can be evaluated as low levels of perceived sharpness, perceived roughness or speed are associated to water sounds which tend to be preferred in the context of peacefulness and relaxation. This is in line with the findings obtained by Galbrun and Ali (2013), according to which water features (such as the natural stream, ST) with low sharpness tend to be preferred on average. On the contrary, the sharper or rougher the water sound was judged, such as NJT and PEW, the more negatively it was rated in the audio-only tests in terms of peacefulness and relaxation,

Table 5.6 Correlations (correlation coefficients, ρ, Spearman test) between semantic attributes and audio-only preferences for each water feature considered.

	Relaxation	Naturalness	Freshness	Familiarity	Perceived sharpness	Perceived roughness	Speed	Envelopment	Temporal variation
ST	0.08	-0.19	-0.26	-0.10	0.13	-0.05	**0.35***	0.22	-0.02
FTW	-0.08	-0.08	-0.14	-0.05	-0.08	-0.01	0.23	**-0.35***	0.004
CA	-0.2	-0.09	0.03	0.05	0.12	0.14	0.21	0.14	**-0.34***
FF	0.11	0.11	-0.11	0.00	0.24	0.15	0.10	0.18	0.30
DF	0.06	0.06	-0.20	-0.06	-0.14	-0.04	-0.17	-0.11	0.01
LJT	**-0.44****	**-0.44****	**-0.58****	-0.22	0.25	**0.46****	0.17	-0.18	0.18
SEW	-0.27	-0.27	-0.13	**-0.35***	0.04	0.14	0.08	0.03	0.14
SHW	-0.24	-0.24	**-0.37***	-0.20	-0.61	0.22	-0.30	-0.18	0.04
NJT	**-0.36***	**-0.36***	**-0.45***	-0.20	**0.34***	**0.31***	**0.38***	**-0.36***	0.22
PEW	-0.16	-0.16	-0.30	**-0.37***	0.05	0.04	-0.07	-0.20	0.06

*Significant correlation at the 0.05 level; ** Significant correlation at the 0.01 level.

Table 5.7 Correlations (correlation coefficients, ρ, Spearman test) between components/attributes affecting sounds characterisation and subjective preferences obtained from both audio-only tests.

Component	Correlation (ρ) with audio-only pref.	Attributes	Correlation (ρ) with audio-only pref.
1-"Emotional assessment"	0.82^{**}	Relaxation	0.83^{**}
		Naturalness	0.69^{*}
		Familiarity	0.57
		Freshness	0.83^{**}
2-"Sound quality"	-0.88^{**}	Perceived sharpness	-0.75^{*}
		Perceived roughness	-0.79^{**}
		Speed	-0.57
3-"Envelopment and temporal variation"	-0.30	Temporal variation	-0.40
		Envelopment	-0.20

although it should be noted that NJT and PEW are not characterised acoustically by high sharpness and high roughness. The contradiction between psychoacoustical data and semantic characterisation of NJT and PEW sounds might be attributed to the difficulty of subjects in correctly judging water sounds in terms of sound quality. This is further discussed in section 5.3.6. From the results obtained, it can be concluded that all the attributes related to "emotional assessment" as well as the perceived sharpness and the perceived roughness, had an important role in waterscapes' perception. On the contrary, speed, temporal variation and envelopment might not be relevant in rating water sounds.

Finally, it is worth noting the inconsistency between the negative sign of correlations found between components 2 and 3 with audio-only preferences (Table 5.7) and the positive sign found for coefficients $\beta_{Sound\ Qual}$ and $\beta_{Env\ \&\ Temp\ Var}$ of the logit model (Table 5.9) and coefficient $b_{Sound\ Qual}$ of the multiple linear regression model (Table 5.11). This was attributed to the fact that average values of different semantic attributes included in each component were used to run the logit model as well as the multiple linear regression model, while the analysis of correlations was based on scores of each attribute considered.

5.2.5 Binary logit model for predicting audio-only preferences in relation to semantic components

Logistic regression was adopted in order to determine the relationship of audio-only preferences (dependent variable, Y) and the semantic components (independent variables, X_n). Results obtained to predict preferences in relation to the semantic attributes are not presented here, because the logit model showed an unacceptable level of accuracy.

Regarding preferences' evaluation in relation to the semantic components, the dependent variables consisted of the preferences expressed for the ten waterscapes considered in this study and obtained from the paired comparisons in the audio-only conditions (45 paired comparisons for each test). Preferences were considered as the frequency with which each water feature had been selected out of 45 paired comparisons for the audio-only tests. In order to carry out a multinomial logistic regression, these preferences were assigned to ten categories (categories 0 to 9, e.g. category 0 includes responses rated between 0 and 1 which correspond to the number of times that each water feature had been selected), whilst the independent variables consisted of average scores obtained from all attributes included in each semantic component. Results obtained from the multinomial logistic regression analysis did not show a relevant significance in discovering a relationship with semantic components. Results from a multinomial linear regression are provided at the end of this section in order to validate the results obtained from the logit model.

In the binary logistic regression, the dependent variable must be dichotomous and categorical (2 categories: category 1 (high level of preference) and category 0 (low level of preference)). The outcome of logistic regression is to predict the probability of an event occurring. In this case, the probability of a high level of preference (category 1) in perceiving different water sounds was predicted in view of improving relaxation and peacefulness in the presence of road traffic noise in the audio-only test condition. This probability was estimated by taking into account the impact of "emotional assessment", "sound quality", "envelopment and temporal variation" on subjective perception.

All data collected from audio-only and semantic differential tests were used to model the binary logistic regressions for sound preferences. The responses from audio-only tests were collected by using ten different waterscapes by presenting the stimuli as paired comparisons (45 paired comparisons) (see Chapter 4 for details). The dependent variables (audio-only preferences) were dichotomized by assigning the two categories 0 and 1 to the scores obtained from audio- only tests: 0 corresponded to low levels of preference whilst 1 was used for high levels of preference in improving relaxation. The category 0 was assigned to responses rated between 0 and 4 (the numbers of time in

Table 5.8 Audio-only preferences expressed as number of subjects (out of 38) in each binary category for the ten water sounds considered (category 0 includes responses rated between 0 and 4 from the audio-only paired comparisons and category 1 corresponds to responses rated between 5 and 9).

	Audio-only preferences									
	CA	ST	SEW	SHW	PEW	FF	DF	FTW	LJT	NJT
Category 0	10	4	24	24	33	17	17	5	21	29
Category 1	28	34	14	14	5	21	21	33	17	9

which a water sound had been selected), whilst the category 1 was assigned to audio-only scores between 5 and 9 (Table 5.8). The responses from the semantic differential test were considered as average rating obtained from all attributes included in each component (e.g., average score between relaxation, naturalness, familiarity and freshness in the case of component 1), based on a ± 2 scale (e.g. -2 = very stressful, -1 = stressful, 0 = neither stressful nor relaxing, 1 = relaxing, 2 = very relaxing).

<u>Logit model for audio-only preferences</u>

Results obtained from the binary logistic regression model showed that audio-only preferences can be predicted by evaluating the three semantic components with a 66.3% of accuracy. The equation for audio-only preferences in relation to the semantic components is the following:

$$PREF_{Audio-only} = \alpha + \beta_{Emot\ Assess} EMOT\ ASSESS + \beta_{Sound\ Qual}\ SOUND\ QUAL + \beta_{Env\ \&\ Temp\ Var} ENV\ \&\ TEMP\ VAR \tag{5.1}$$

where $PREF_{Audio\text{-}only}$ is the dependent variable calculated by the logit model (range -∞ to +∞), and *EMOT ASSESS*, *SOUND QUAL*, and *ENV & TEMP VAR* are the independent variables (average ratings for each component, in the range -2 to +2). The modelling data obtained for equation (5.1) is given in Table 5.9 (more detailed information about the statistical method of logit model can be found in section 3.4.1 of Chapter 3). The Nagelkerke R^2 (analogous of the R^2 value applied in the linear regression) was used to predict the goodness of the fit of the model, and this was equal to 0.17 (reasonable fit) (Burns and Burns, 2008). Furthermore, the likelihood ratio test based on the *-2LL* ratio (Burns and Burns, 2008) was significant at the 0.05 level ($p < 0.05$), meaning that the model with all the predictors (independent variables) was significantly different from the one including only the constant (the null hypothesis (H_0) can be rejected: the null

Table 5.9 Logit model data for predicting audio-only preferences in relation to semantic components. The model fitting information.

Accuracy of predicting the model			66.3%	
Nagelkerke R^2 (range 0-1)			0.17	
Predictors	Coefficient (β;α)	p – value	*Odds- ratio* [*exp*(β)]	*Wald*
EMOT ASSESS	1.18	0.00**	3.25[a]	38.97
SOUND QUAL	0.18	0.38	-	1.19
ENV & TEMP VAR	0.02	0.89	-	1.02
Constant α	-0.32	0.01	0.72	0.72

**Significant correlation at the 0.01 level ($p < 0.01$).
[a]Increase in odds of positively rating water sounds if subjects positively rate the "emotional assessment."

hypothesis occurs when all the coefficient β in the regression equation take the value zero). The Wald statistic (W) and associated probabilities provide an index of significance of each predictor for equation (5.1). If the probability associated to the Wald statistic's value is less than 0.05, the predictors do make a significant contribution to the model. The most important finding of this logit model is that EMOT ASSESS is the only independent variable to be a statistically significant predictor for the model ($p < 0.01$) (Table 5.9), confirming that "emotional assessment" explains most preferences. The positive sign found for $\beta_{EMOT\ ASSESS}$ in Table 5.9 also indicated that the likelihood in giving a positive audio-only rating increases as the rating of "emotional assessment" increases. This means that if the "emotional assessment" increases by one unit (within the -2 to +2 range), the odd-ratio (*exp(β)*) is 3.25 times as large. In other words, people are 3.25 more times likely belonging to category 1 (high levels of preference in listening to water sounds that improve relaxation in the presence of road traffic noise).

In order to understand the usefulness of the model given by equation (5.1), it is important to note that the outcome of logistic regression is not a prediction of the dependent variable's value ($PREF_{Audio\text{-}only}$), as in the linear regression, but a probability, $P(PREF_{Audio\text{-}only})$, of belonging to one of the two conditions used as input data for $PREF_{Audio\text{-}only}$. In this case, it is the probability of a high level of preference (category 1) from the water sounds in terms of relaxation and peacefulness, and the probability can be expressed as (Burns and Burns, 2008):

$$P(PREF_{Audio-only}) = \frac{1}{1 + e^{-(PREF_{Audio-only})}} \tag{5.2}$$

Table 5.10 Logit model data for predicting audio-only preferences in relation to semantic components. The probability of high level of preference based on eq. (5.1), with $\beta_{SOUND\ QUAL} = \beta_{ENVIR\ \&\ TEMP\ VAR} = 0$ (i.e., "emotional assessment" component used as the only predictor).

EMOT ASSESS [-2, +2]	$PREF_{Audio\text{-}only}$ [-∞;+∞]	Probability of high levels of preference [0;1]
-2	-2.68	0.06
-1	-1.50	0.18
0	-0.32	0.42
+1	0.86	0.70
+2	2.04	0.80

The probability of high levels of preference was calculated by considering the predictive equation (5.2), and results are given in Table 5.10. Results were obtained for the logit model as a function of the actual value of *EMOT ASSESS* values and the $PREF_{Audio\text{-}only}$ values calculated from equation (5.1) with $\beta_{SOUND\ QUAL} = \beta_{ENVIR\ \&\ TEMP\ VAR} = 0$ (components ignored because not statistically significant in the model). When "emotional assessment" was within the -2 to 0 ranges, the audio-only preferences, $PREF_{Audio\text{-}only}$, had negative values and the probability of high levels of preference, $P(PREF_{Audio\text{-}only})$ was between 0.06 and 0.42. On the contrary, positive values related to the emotional component of water sounds, corresponded to a probability that was between 0.42 and 0.80. This means that the probability of belonging to category 1 (high level of preference) was at least 70% for an "emotional assessment" rating of +1 or more (on a -2 to +2 range).

Multiple linear regression

In order to compare the contributions of the semantic components on the acoustic preferences, a multiple linear regression was also conducted, even though the R^2 value of linear regression was smaller than that of logistic regression. This analysis was run using the method of least squares, and the significance of R^2 was tested through the use of the *F-ratio* (value of F should be greater than 1 and there is a statistical significance when probability p associated to F is less than 0.5) (Burns and Burns, 2008). The multiple linear regression was conducted using the three principal components ("emotional assessment", "sound quality" and "envelopment and temporal variation") as independent variables. The outcome consisted of predicting audio-only preferences $PREF_{Audio\text{-}only}$ (dependent variable) from the combination of the independent variables

Table 5.11 Multiple linear regression data for predicting audio-only preferences in relation to semantic components. The model fitting information.

Predictors	Coefficient (b; b_0)	t-test	p value	95% Confidence interval	
				Lower bound	Upper bound
EMOT ASSESS	1.48	7.87	**0.00****	1.11	1.84
SOUND QUAL	0.38	1.70	0.08	-0.05	0.82
ENV & TEMP	-0.05	-0.30	0.76	-0.42	0.31
Constant b_0	4.01	29.72	**0.00****	3.74	4.27

**Significant correlation at the 0.01 level ($p < 0.01$).

(*EMOT ASSESS*, *SOUND QUAL*, *ENV & TEMO VAR*) multiplied by their respective coefficients ($b_{EMOT\ ASSESS}$, $b_{SOUND\ QUAL}$, $b_{ENV\ \&\ TEMP\ VAR}$), and can be expressed as:

$$PREF_{Audio-only} = b_0 + b_{Emot\ Assess} EMOT\ ASSESS + b_{Sound\ Qual}\ SOUND\ QUAL + b_{Env\ \&\ Temp\ Var} ENV\ \&\ TEMP\ VAR \tag{5.3}$$

The value of R^2 was equal to 0.16 and the associated *F-ratio* was 24.31, with a statistical significance at the 0.05 level ($p < 0.05$) [$R^2 = 0.16$, $F(3,376) = 24.31$] (Table 5.11).

The multiple linear regression provided exactly the same findings of the logit regression, as significant relation was found only between "emotional assessment" and audio-only preferences. Predictions of audio-only preferences $PREF_{Audio-only}$ can be found by using equation (5.4):

$$PREF_{Audio-only} = 4.01 + 1.48 \cdot EMOT\ ASSESS \tag{5.4}$$

5.2.6 Correlations between semantic components/attributes and acoustic/psychoacoustic parameters

The analysis of correlations (Spearman test) was made in order to identify the relationship between the qualitative assessment of different waterscapes used over road traffic noise and the physical properties of the corresponding sounds. Results showed that temporal variation in level (L_{A10}-L_{A90}) positively and strongly correlates ($p < 0.05$) with component 3, as shown in Table 5.12. Roughness was also found to be positively correlated and strongly ($p < 0.05$) with components 2 and 3. Additionally, a significant

Table 5.12 Correlations (correlation coefficients ρ, Spearman test) between semantic components and acoustic /psychoacoustic parameters calculated from sound including water sound with road traffic noise.

	Component 1 "Emotional assessment"	Component 2 "Sound quality"	Component 3 "Envelopment and temporal variation"
L_{A10}-L_{A90} (dB)	0.70	0.45	0.75*
L_{Ceq}-L_{Aeq} (dB)	0.45	0.13	-0.20
Sharpness (acum)	-0.18	-0.33	-0.50
Roughness (asper)	-0.17	0.67*	0.71*
Pitch strength	-0.64*	0.14	0.24

* Correlation is significant at the 0.05 levels (p < 0.05).

correlation ($p < 0.05$, negative and high correlation) was obtained for pitch strength in relation to component 1. Overall, it can be observed that the significant correlations obtained do not provide a clear explanation in finding a relationship between individual physical parameters and semantic components of water sounds.

Furthermore, the analysis carried out between average scores obtained for each semantic attributes and acoustic/psychoacoustic parameters (given in Table 5.13) showed that sharpness is negatively correlated to the attributes speed ($p < 0.01$) and envelopment ($p < 0.05$). A similar trend was found for roughness that is significantly correlated with speed ($p < 0.01$) and envelopment ($p < 0.05$). It can be also noted that temporal variation in level (L_{A10}-L_{A90}) positively correlated with speed and envelopment ($p < 0.01$). Additionally, pitch strength was negatively correlated to familiarity ($p < 0.05$). These results suggest that no correlations were found between physical parameters and their corresponding perceptual descriptors. Overall, there is no clear trend in finding a unique relationship between individual acoustic/psychoacoustic parameters and ratings from the qualitative characterisation of water sounds in the presence of road traffic noise. It can be noted that physical properties of sounds had no influence in rating emotional attributes of different water sounds. On the contrary, it was found that higher temporal variation in level, lower sharpness and higher roughness helped people to highly rate water sounds in terms of speed and envelopment.

Table 5.13 Correlations (correlation coefficients ρ, Spearman test) between semantic attributes obtained from the qualitative characterisation of waterscapes and acoustic/psychoacoustic parameters calculated from sounds including water sounds combined with road traffic noise.

	COMPONENT 1 “Emotional Assessment”				COMPONENT 2 “Sound quality”			COMPONENT 3 “Envelopment and temporal variation”	
	Relaxation	Naturalness	Familiarity	Freshness	Perceived sharpness	Perceived roughness	Speed	Envelopment	Temporal variation
L_{A10}-L_{A90} (dB)	-0.12	0.31	0.17	0.01	-0.26	-0.05	**0.88****	**0.79****	-0.55
L_{Ceq}-L_{Aeq} (dB)	0.17	0.39	0.42	0.22	-0.20	-0.34	0.22	0.11	-0.21
Sharpness (acum)	0.11	-0.37	-0.33	0.51	0.18	0.20	**-0.76****	**-0.68***	0.59
Roughness (asper)	-0.26	0.03	-0.12	0.25	0.22	0.24	**0.85****	**0.74***	-0.47
Pitch strength	-0.35	-0.57	**-0.64***	0.21	0.39	0.60	-0.07	-0.07	0.28

* Correlation is significant at the 0.05 levels ($p < 0.05$) ** Correlation is significant at the 0.01 levels ($p < 0.01$).

5.2.7 Discussion

The semantic differential method was adopted to evaluate the qualitative characterisation of the ten waterscapes tested in the perceptual preferences tests. Nine qualitative attributes (relaxation, naturalness, freshness, familiarity, perceived sharpness, perceived roughness, speed, envelopment and temporal variation) were used to describe the ten water sounds based on a five-point numerical scale by using nine antonymous adjectives.

Three principal components were identified as important in the characterisation of different waterscapes used over road traffic noise in the context of peacefulness and relaxation. Component 1, called "emotional assessment", was related to the subjective preferences produced by emotional attributes of sounds, and its attributes included relaxation, freshness, naturalness and familiarity. Components 2 and 3 were related to psychoacoustical and physical properties of sounds. Component 2, called "sound quality" consisted of perceived sharpness, perceived roughness and speed; whilst component 3 ("envelopment and temporal variation") included envelopment and temporal variation.

Results pointed out that water sounds defined by the words relaxation, freshness, naturalness and familiarity like ST and CA, tend to be preferred. This suggested that sound properties related to emotional attributes might be used together in improving waterscapes' perception in the context of peacefulness.

Results obtained for component 2 ("sound quality") showed that people are not able to correctly make judgement on sound quality: the perceived sharpness and perceived roughness did not always correspond to the equivalent values of sharpness and roughness calculated for the water sounds considered. The exception was represented by the good agreement between the low perceived sharpness expressed for the natural shallow stream (ST) and its calculated value of sharpness. However, it is interesting to note that differences in the calculated sharpness and roughness among different water sounds were less noticeable. Additionally, water sounds, such as NJT and LJT, were defined by the adjective directional and tended not to be preferred in the perceptual preferences' tests. Finally, it was interesting to note that people rated envelopment as a quality for which no direction can be associated to the sound, rather than a well-defined stereo field (i.e. not even a combination of right and left channels, as in the case of ST).

The analysis of correlations (Spearman test) showed a positive relationship between component 1 and preferences obtained from the audio-only tests. On the contrary, component 2 correlated negatively with audio-only ratings of water features. Additionally, no correlation was found between component 3 and audio-only preferences. Significant negative correlations with preferences were found in particular for perceived sharpness and perceived roughness. This negative impact on perception of water sounds could be interpreted in a positive way: the more the water sounds were defined by low perceived sharpness and low perceived roughness, the more they tended to be preferred. Overall, it can be concluded that all attributes related to "emotional assessment", as well as the perceived sharpness and the perceived roughness of component 2 can strongly affect waterscapes' perception in the context of peacefulness.

The logit model obtained for predicting audio-only preferences in relation to the semantic components aimed at evaluating the probability of high levels of preference in perceiving different water features used over road traffic noise in view of improving relaxation and peacefulness. Subjective perception was found to be mainly affected by "emotional assessment". This means that the more the ten waterscapes were positively assigned to emotional attributes of sounds, the more subjective perception improved in terms of relaxation and peacefulness in the presence of road traffic noise. Additional analysis including a multiple linear regression further confirmed the main findings obtained from the logit binary regression.

Additionally, no clear trend was found to identify a unique relationship between semantic components/attributes and acoustic/psychoacoustic parameters for the water sounds considered in the study presented here. No correlations were found between sharpness, roughness and temporal variations and their corresponding perceptual descriptors, suggesting that people were unable to correctly assess these sound qualities for water sounds used over road traffic noise. On the contrary, the perception of speed and envelopment were strongly correlated with acoustic (L_{A10}-L_{A90}) and psychoacoustic (sharpness and roughness) parameters.

5.3 Conclusions

Results obtained from the semantic differential test identified three principal components ("emotional assessment", "sound quality" and "envelopment and temporal variation") affecting sound perception of the ten water features used over road traffic noise. "Emotional assessment" was related to the emotional attributes of sounds and includes relaxation, naturalness, freshness and familiarity. "Sound quality" and "envelopment and temporal variation" were related to psychoacoustical and physical properties of sounds.

“Sound quality” consisted of perceived sharpness, perceived roughness and speed, whilst “envelopment and temporal variation” included envelopment and temporal variation.

A significant positive correlation was found between component 1 and preferences obtained from the audio-only tests. Water features highly rated for “emotional assessment” tended to be preferred. In addition, relaxation, freshness and naturalness were found to be positively correlated with preferences. This suggested that these qualitative attributes, included in component 1, might be used together for the soundscape design of water features in the context of peacefulness. On the contrary, component 2 was found to be negatively correlated with preferences in uni-modal sensorial conditions. A significant negative correlation between the perceived sharpness and the perceived roughness and preferences was also found. Water sounds defined by lower perceived sharpness and lower perceived roughness, tended to be preferred. Finally, it is worth mentioning that people rated envelopment as a quality for which no direction can be associated to the sound, rather than a well-defined stereo field.

The logit binary model obtained for predicting preferences in relation to the semantic components showed that subjective perception is mainly affected by “emotional assessment”. This suggested that the more the waterscapes are positively assigned to emotional attributes of sounds, the more subjects are expected to perceive water sounds with a high level of preference when they are used over road traffic noise in the context of relaxation and peacefulness. Additionally, a linear multiple regression was also run using the three principal semantic components, in order to predict audio-only preferences, and this provided exactly the same findings obtained from the logit model: “emotional assessment” is the most important component, being the only significant predictor.

The analysis of correlations between perceptual components of water sounds and corresponding acoustic/psychoacoustic parameters highlighted no clear trend to identify a unique relationship. Results suggested that people are unable to correctly assess the sharpness, roughness and speed of water sounds, as no correlations were found between physical parameters and their corresponding perceptual descriptors. On the contrary, the perception of speed and envelopment were found to be strongly correlated with acoustic (L_{A10}-L_{A90}) and psychoacoustic (sharpness and roughness) parameters.

CHAPTER 6

Categorisation and Evocation of Water Sounds used over Road Traffic Noise[1]

6.1 Introduction

The analysis presented in this chapter illustrates the categorisation and evocation of different water sounds used over road traffic noise in view of understanding how these aspects can affect preferences of water sounds (objective 5, as shown in section 1.3 of Chapter 1). Results obtained in terms of sound categorisation (waterfall vs. fountain vs. stream) are then illustrated and discussed. The analysis based on sounds' identification was then examined in view of identifying manmade water sounds evocation as well rainfall evocation. Additionally, results obtained from the qualitative "open-ended" descriptions of water sounds are given (detailed results of this analysis can be found in Appendix F). Finally, results from the visual categorisation (manmade vs. natural) are presented. A critical discussion is given for each section, and conclusions are illustrated at the end of the chapter.

6.2 Qualitative sound categorisation (waterfall vs. fountain vs. stream)

Qualitative categorisation of water sounds was examined in view of understanding how it can affect subjective perception. Table 6.1 shows scores in terms of percentages obtained for the water features in each perceived category. Water features were classified in three objective categories (1 – waterfall; 2 – fountain; 3 – natural stream) (refer to Table 3.1 for details of water features). The perceived categories included in the questionnaire were *waterfall* (1), *fountain* (2), *natural stream* (3) and *none of these* (4). The large jet (LJT) was assigned to both objective categories 2 and 3, i.e. it was considered as a fountain as well as a stream. It was assigned to category 3 due its shallow and irregular distribution of water as suggested by Galbrun and Ali (2013): the presence of a low pressure at its large nozzle' opening generated a unsteady operation of the pump and a high value of L_{A10}-L_{A90} (Galbrun and Ali, 2013). Percentages obtained for each perceived category have been colour coded in Table 6.1

[1]Some sections of this chapter are based on the paper: L. Galbrun and F.M.A. Calarco, "Audio-visual interaction and perceptual assessment of water features used over road traffic noise", *J. Acoust. Soc. Am.*, **136(5)**, 2609–2620, (2014).

Table 6.1 Percentage of each perceived category and corresponding correlations (correlation coefficients ρ, Spearman test). Tests were carried out with sounds including water sounds combined with road traffic noise.

[0,10] %	[11,20] %	[21,30] %	[31,40] %	[41,50] %	[51,60] %	[61,70] %	[71,80] %	[81,90] %	[91,100] %

Water Feature	Objective Category	Perceived category 1 (%)	Perceived category 2 (%)	Perceived category 3 (%)	Perceived category 4 (%)
PEW	1 - Waterfall	42.1	0	7.9	50
SEW	1 - Waterfall	23.7	18.4	39.5	18.4
SHW	1 - Waterfall	28.9	10.5	13.2	47.4
FTW	2 - Fountain	18.4	23.7	23.7	34.2
DF	2 - Fountain	34.2	10.5	21.1	34.2
FF	2 - Fountain	5.3	34.2	23.7	36.8
LJT	2/3 –Fountain/Natural stream	10.5	28.9	13.2	47.4
NJT	2 - Fountain	10.5	36.8	7.9	44.7
CA	3 – Natural stream	18.4	5.3	65.8	10.5
ST	3 – Natural stream	2.6	13.2	78.9	5.3
Coefficient correlation (ρ)		0.65*	0.70* / 0.53	0.70* / 0.46	-

* Correlation is significant at the 0.05 level ($p < 0.05$); Perceived category 1 = waterfall, Perceived category 2 = fountain, Perceived category 3 = natural stream, Perceived category 4 = none of these. Two correlation coefficients given for perceived categories 2 and 3: the value on the left corresponds to LJT being assigned to objective category 2, whilst the value on the right corresponds to LJT being assigned to objective category 3.

(dark colours corresponding to higher percentages).

6.2.1 Results

In Table 6.1, the percentages corresponding to each perceived category as well as correlations (Spearman test) between the perceived and objective categories are shown. It can be noted that correlation coefficients were calculated for the two categories assigned to LJT: the value on the left corresponds to LJT being assigned to objective category 2, whilst the value on the right corresponds to LJT being assigned to objective category 3.

Results obtained as percentages of each perceived category show that participants were unable to categorise most of the water sounds, as most percentages occurred in perceived category 4 (*none of these*). An exception was represented by the natural shallow stream (ST) and the cascade (CA), which were clearly identified by participants as natural stream sounds (category 3). The latter was also confirmed by results obtained from the qualitative description which is illustrated later in section 6.4.3 (Table 6.6). The dome fountain (DF) was identified as a waterfall. All remaining water features were attributed to perceived category 4. This suggested that sounds from natural streams and cascades could be recognised correctly, whilst the categorisation into waterfalls and fountain was more difficult. However, participants not selecting *none of these* (around 60% of participants on average (excluding ST and CA responses)) tended to accurately identify the type of water that they heard. Furthermore, if perceived category 4 (*none of these*) is ignored, results suggest that, on average, waterfalls could be more easily identifiable than fountains.

The analysis of correlations (Spearman test) showed a significant high and positive correlation between the perceived and objective category 1 (*waterfall*) ($\rho = 0.65$, $p < 0.05$). Additionally, it was found that perceived category 2 (*fountain*) correlates positively and strongly with the corresponding objective category when LJT is categorised as a fountain ($\rho = 0.70$, $p < 0.05$). The same trend was observed between the perceived and objective category 3 (*natural stream*) ($\rho = 0.70$, $p < 0.05$).

The relationship between perceived categories for each sound and the corresponding acoustic/psychoacoustic parameters was then studied by analysing ranking positions of individual water sounds as well as ranking sounds' groups and correlations (Spearman test) (similar procedure used in section 4.3). Table 6.2 shows the analysis based on results obtained from percentage of selection of "perceived natural stream". A significant high correlation was found between average scores based on the percentages of perceived natural stream and the normalised preferences from the audio-only test. This positive relationship suggests that the more the water features were perceived as natural streams, the more they were preferred in the audio-only test.

The analysis between results obtained in terms of perceived waterfall and acoustic/psychoacoustic parameters (Table 6.3) showed a significant correlation with temporal variation (L_{A10}-L_{A90}) (negative and high correlation) ($p < 0.05$) and roughness (negative and high correlation) ($p < 0.01$). It can be noted that, on average, sounds with lower temporal variation and lower roughness were assigned to the perceived category of waterfalls. However, no correlation was found between audio-only preferences and scores obtained for the perceived waterfall category.

Rankings obtained in terms of perceived fountain showed a significant correlation

Table 6.2 Percentage of selection of “perceived natural stream” (Table 6.1) and corresponding correlations (correlation coefficients ρ, Spearman test) with normalised preferences from the audio-only test and acoustic/psychoacoustic parameters calculated from sounds including water sounds combined road traffic noise.

Perceived natural stream			Audio-only ratings	L_{A10}-L_{A90}	L_{Ceq}-L_{Aeq}	Sharpness	Roughness	Pitch strength
Ranking	Sound code	%	Norm. Pref.	(dB)	(dB)	(acum)	(asper)	
1	ST	0.79	1.16	1.70	2.5	1.61	0.21	0.08
2	CA	0.66	0.55	1.40	2.7	1.71	0.09	0.08
3	SEW	0.39	-0.19	1.60	2.7	1.59	0.05	0.07
4	FTW	0.24	0.67	1.50	2.7	1.67	0.08	0.08
5	FF	0.24	0.12	1.60	2.8	1.61	0.09	0.07
6	DF	0.21	0.08	1.40	2.5	1.70	0.05	0.08
7	LJT	0.13	-0.07	2.10	2.9	1.42	0.19	0.07
8	SHW	0.13	-0.30	1.40	2.5	1.71	0.04	0.08
9	NJT	0.08	-0.81	1.60	2.5	1.67	0.16	0.08
10	PEW	0.08	-1.20	1.40	2.8	1.70	0.04	0.07
Correlation coefficient (ρ)			0.83**	0.18	-0.1	-0.18	0.33	0.18

** Significant correlation at the 0.01 level.

Table 6.3 Percentage of selection of “perceived waterfall” (Table 6.1) and corresponding correlations (correlation coefficients ρ, Spearman test) with normalised preferences in the audio-only test and acoustic/psychoacoustic parameters calculated from sounds including water sounds combined road traffic noise.

Perceived waterfall			Audio-only ratings	L_{A10}-L_{A90}	L_{Ceq}-L_{Aeq}	Sharpness	Roughness	Pitch strength
Ranking position	Sound code	%	Norm. Pref.	(dB)	(dB)	(acum)	(asper)	
1	PEW	0.42	-1.20	1.40	2.8	1.70	0.04	0.07
2	DF	0.34	0.08	1.40	2.5	1.70	0.05	0.08
3	SHW	0.29	-0.30	1.40	2.5	1.71	0.04	0.08
4	SEW	0.24	-0.19	1.60	2.7	1.59	0.05	0.07
5	CA	0.18	0.55	1.40	2.7	1.71	0.09	0.08
6	FTW	0.18	0.67	1.50	2.7	1.67	0.08	0.08
7	LJT	0.11	-0.07	2.10	2.9	1.42	0.19	0.07
8	NJT	0.11	-0.81	1.60	2.5	1.67	0.16	0.08
9	FF	0.05	0.12	1.60	2.8	1.61	0.09	0.07
10	ST	0.03	1.16	1.70	2.5	1.61	0.21	0.08
Correlation coefficient (ρ)			-0.55	-0.80*	-0.04	0.53	-0.90**	-0.03

** Significant correlation at the 0.01 level; * Significant correlation at the 0.05 level

Table 6.4 Percentage of selection of "perceived fountain (Table 6.1) and corresponding correlations (correlation coefficients ρ, Spearman test) with normalised preferences in the audio-only test and acoustic/ psychoacoustic parameters calculated from sounds including water sounds combined road traffic noise.

Perceived fountain			Audio-only ratings	L_{A10}-L_{A90}	L_{Ceq}-L_{Aeq}	Sharpness	Roughness	Pitch strength
Ranking position	Sound code	%	Norm. Pref.	(dB)	(dB)	(acum)	(asper)	
1	NJT	0.37	-0.81	*1.60*	*2.5*	*1.67*	*0.16*	*0.08*
2	FF	0.34	0.12	*1.60*	*2.8*	*1.61*	*0.09*	*0.07*
3	FTW	0.24	0.67	*1.50*	*2.7*	*1.67*	*0.08*	*0.08*
4	LJT	0.29	-0.07	*2.10*	*2.9*	*1.42*	*0.19*	*0.07*
5	SEW	0.18	-0.19	*1.60*	*2.7*	*1.59*	*0.05*	*0.07*
6	ST	0.13	1.16	*1.70*	*2.5*	*1.61*	*0.21*	*0.08*
7	DF	0.11	0.08	*1.40*	*2.5*	*1.70*	*0.05*	*0.08*
8	SHW	0.11	-0.30	*1.40*	*2.5*	*1.71*	*0.04*	*0.08*
9	CA	0.05	0.55	*1.40*	*2.7*	*1.71*	*0.09*	*0.08*
10	PEW	0.00	-1.20	*1.40*	*2.8*	*1.70*	*0.04*	*0.07*
Correlation coefficient (ρ)			0.07	*0.73**	*0.09*	*-0.6**	*0.56*	*-0.14*

** Significant correlation at the 0.01 level; * Significant correlation at the 0.05 level

with temporal variation (L_{A10}-L_{A90}) (positive and high correlation) as well as sharpness (negative and high correlation) ($p < 0.05$) (Table 6.4).

Further analysis indicated no significant differences in responses between different cultural groups (Kruskal-Wallis test, $p > 0.05$), ages and genders (Mann-Whitney test, $p > 0.05$). An exception is represented by the significant differences in responses found between different genders for LJT (Mann-Whitney test, $p < 0.05$). Among 38 participants, LJT was perceived as a waterfall by 8 females and by only 3 males, as a fountain by 3 females and by only 1 male, and as a natural stream by 3 females and by only 2 males. The remaining 18 participants (5 females and 13 males) were not able to classify it.

6.2.2 Discussion

The categorisation (waterfall vs. fountain vs. stream) of different water features was examined in order to identify its effect on sound perception. In terms of sound categorisation, participants had difficulties in identifying sounds from waterfalls and fountains. However, they were able to recognise sounds from the natural stream (ST) and the cascade (CA). Furthermore, results suggested that waterfalls were more identifiable than fountains if perceived category 4 (*none of these*) was ignored.

A significant correlation was also found between scores obtained from perceived category 3 (*natural stream*) and audio-only preferences. In fact, water sounds identified as natural stream sounds tended to be preferred in the audio-only tests. No correlations were found between the perceived natural stream and acoustic/psychoacoustic parameters. Results also indicated that sounds including water sounds combined with road traffic noise were assigned to the perceived waterfall category when they had lower temporal variation in level (L_{A10}-L_{A90}) and lower roughness, as significant correlations were found with both parameters. However, no correlation was observed between audio-only preferences and scores obtained for the perceived waterfall. Additionally, a significant correlation was found between scores obtained from the perceived fountain category and temporal variation (L_{A10}-L_{A90}), but normalised preferences from the audio-only tests were not correlated with these. Overall, results indicated weak association between preferences of perceived categories and acoustic/psychoacoustic parameters.

6.3 Evocation of manmade water sounds and rainfall

In order to further examine sounds' identification, tests were also carried out to understand if the water sounds could be associated to a manmade or a natural sound. Participants were asked to listen to the ten water sounds presented individually with road traffic noise and then answer the question "*Does this sound make you think of a manmade water feature*? *(e.g., water falling into a drain/container or a tap)*" by ticking their preference (*yes* or *no*) (Appendix D).

6.3.1 Results: manmade water sound evocation

Results from this analysis showed that sounds generated from jets and the foam fountain (FF) were evocative of manmade water features, as shown in Figure 6.1. On the contrary, sounds from waterfalls (PEW, SHW and SEW), the natural shallow stream (ST), the cascade (CA) and the dome fountain (DF) were clearly associated to natural sounds. It can be noted that the water sounds (NJT and LJT), identified as evocative of manmade sounds, were negatively rated in the audio-only tests, and these were qualitative described as water tap sounds (refer to Table 6.7 of section 6.4.3 for details of the qualitative description of water sounds). On the other hand, the foam fountain

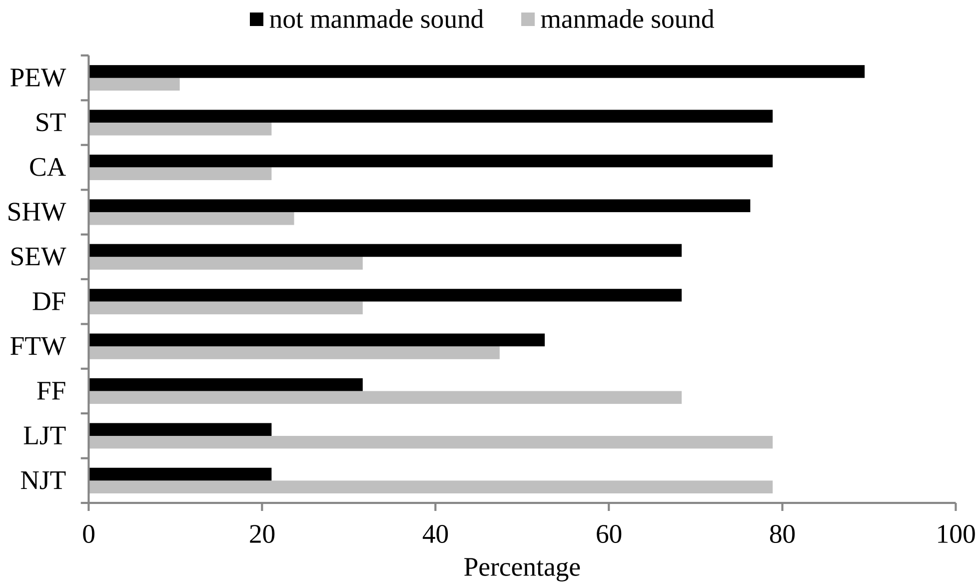


Figure 6.1 Manmade sound evocation for the ten water sounds tested in the presence of road traffic noise (refer to Table 3.1 for definitions and acronyms).

Table 6.5 Ranking positions based on manmade sound evocation, together with audio-only preferences and corresponding acoustic/psychoacoustic parameters calculated from sounds including water sounds combined with road traffic noise. Correlations (correlation coefficients ρ, Spearman test) are also given.

Manmade sounds			Audio-only ratings	L_{A10}-L_{A90}	L_{Ceq}-L_{Aeq}	Sharpness	Roughness	Pitch strength
Ranking position	Sound code	Average score	Norm. Pref.	(dB)	(dB)	(acum)	(asper)	
1	NJT	0.30	-0.81	1.4	2.8	1.7	0.04	0.07
2	LJT	0.30	-0.07	1.4	2.5	1.7	0.04	0.08
3	FF	0.26	0.12	1.5	2.8	1.7	0.05	0.08
4	FTW	0.18	0.67	1.6	2.7	1.59	0.05	0.07
5	DF	0.12	0.08	1.4	2.5	1.7	0.05	0.08
6	SEW	0.12	-0.19	1.4	2.7	1.71	0.09	0.08
7	SHW	0.09	-0.30	1.6	2.8	1.61	0.09	0.07
8	ST	0.08	1.16	1.7	2.5	1.61	0.21	0.08
9	CA	0.08	0.55	1.5	2.7	1.67	0.08	0.08
10	PEW	0.07	-1.20	1.6	2.5	1.67	0.16	0.08
Correlation coefficient (ρ)			-0.05	-0.62	0.35	0.44	-0.89**	-0.3

** Correlation is significant at the 0.01 level ($p < 0.01$).

(FF) was associated to a manmade sound but it had positive ratings in the audio-only preferences. Additionally, water sounds such as PEW, SHW and SEW were selected as natural sounds but were poorly rated in the audio-only tests. Overall, these results suggested that there is no unique relationship between the evocation of manmade sounds and audio-only preferences among all the water features considered in this study. It can also be noted that visual categorisation of manmade water features had a more relevant impact on sound perception rather than manmade sound evocation (refer to section 6.5 for details on the visual categorisation).

Overall, no clear relationship was found between the evocation of manmade sounds, audio-only preferences and the corresponding acoustic/psychoacoustic parameters.

Furthermore, results indicated no significant differences in responses between different ages (Mann-Whitney, $p > 0.05$) and cultural groups (Kruskal-Wallis test, $p > 0.05$) for most water sounds. By contrast, significant differences were found between different genders (19 females and19 males) in the case of NJT, DF and CA (Mann-Whitney, $p < 0.05$). Sounds from the dome fountain and the cascade with four steps were classified as sounds from natural structures by 15 males for DF and 17 males for CA, and by 9 females for DF and 11 females for CA. Furthermore, the narrow jet (NJT) was evocative of a manmade water feature for 19 males (i.e., all males) and 11 females.

6.3.2 Results: rainfall evocation

Additional tests were carried out in view of identifying which water sounds used over road traffic noise were associated to rainfall. Participants were asked to listen to the ten water sounds presented with road traffic noise individually and then answer the question "*Does this sound make you think of rainfall*?" by ticking their preference (*yes* or *no*) (Appendix D).

Results (Figure 6.2) indicated that the small holes' edge waterfall (SHW) and the dome fountain (DF) evoked rainfall to around 80% of the participants, and these sounds were also qualitative described as rainfall (refer to Table 6.7 of section 6.4.3, for details of the qualitative description of water sounds). Furthermore, the waterfall with a plain edge (PEW) and the fountain with 37 upward jets (FTW) resembled rainfall to around 60% of participants. On the contrary, NJT, FF, ST, LJT, CA and SEW were not associated to rainfall. It can also be noted that SHW and PEW were negatively rated in the audio-only tests, whilst FTW and DF tended to be preferred on

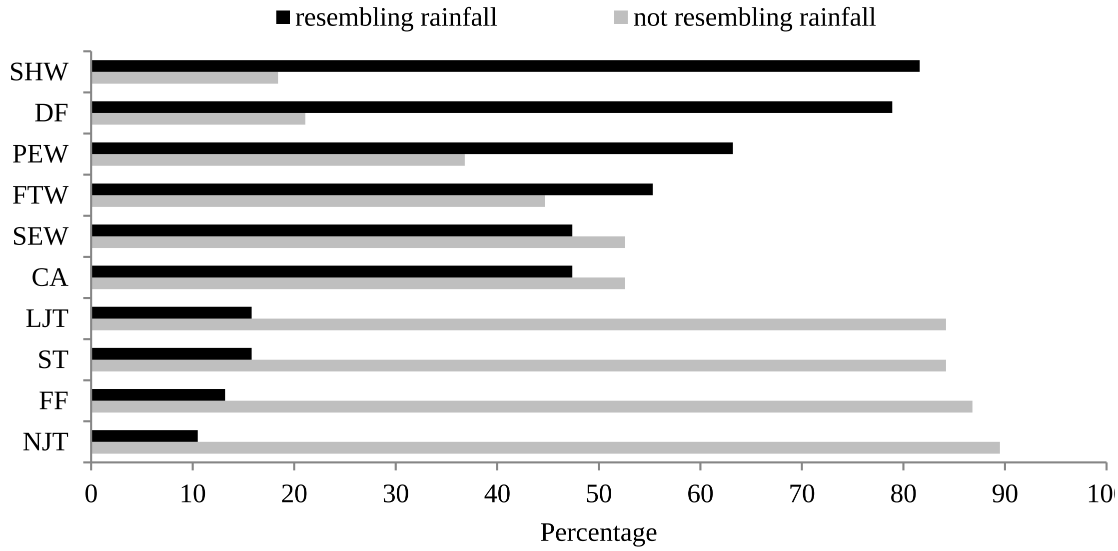


Figure 6.2 Rainfall evocation for the ten water sounds tested in the presence of road traffic noise (refer to Table 3.1 for definitions and acronyms).

average. This suggested that it is not possible to find a clear connection between sound perception and rainfall evocation.

Further analysis showed no significant correlation between average scores obtained from rainfall evocation and normalised audio-only preferences, as well as acoustic/psychoacoustic parameters (Table 6.6). Water sounds evocative of rainfall tended not to be preferred, but the correlation was not significant. Overall, results suggested that there is a weak association between acoustic/psychoacoustic parameters as well as audio-only preferences and the water sounds' evocation of rainfall.

Additionally, no significant differences in responses were found between cultural groups (Kruskal-Wallis test, $p > 0.05$). Conversely, significant differences were found between different genders (19 females and 19 males) in the case of PEW and SEW, and between different ages for NJT (Mann-Whitney, $p < 0.05$). The waterfall with a plain edge was associated to rainfall by 15 females and 9 males, whilst the sound from SEW did not resemble rainfall for 14 males and 6 females. Sounds from the narrow jet (NJT) were classified as not resembling rainfall by participants ranging from 28 to 47 years (mean 37.5 years), whilst participants ranging from 23 to 28 years (mean 25.5 years) associated this sound to rainfall.

Table 6.6 Ranking positions based on rainfall evocation, together with audio-only preferences and corresponding acoustic/psychoacoustic parameters calculated from sounds including water sounds combined with road traffic noise. Correlations (correlation coefficients ρ, Spearman test) are also given.

Rainfall evocation			Audio-only ratings	L_{A10}-L_{A90}	L_{Ceq}-L_{Aeq}	Sharpness	Roughness	Pitch strength
Ranking position	Sound code	Average score	Norm. Pref.	(dB)	(dB)	(acum)	(asper)	
1	SHW	0.31	-0.30	*1.6*	*2.8*	*1.61*	*0.09*	*0.07*
2	DF	0.3	0.08	*2.1*	*2.9*	*1.42*	*0.19*	*0.07*
3	PEW	0.24	-1.20	*1.6*	*2.5*	*1.67*	*0.16*	*0.08*
4	SEW	0.18	-0.19	*1.4*	*2.7*	*1.71*	*0.09*	*0.08*
5	CA	0.18	0.55	*1.5*	*2.7*	*1.67*	*0.08*	*0.08*
6	FTW	0.17	0.67	*1.6*	*2.7*	*1.59*	*0.05*	*0.07*
7	LJT	0.06	-0.07	*1.4*	*2.5*	*1.7*	*0.04*	*0.08*
8	ST	0.06	1.16	*1.7*	*2.5*	*1.61*	*0.21*	*0.08*
9	FF	0.05	0.12	*1.5*	*2.8*	*1.7*	*0.05*	*0.08*
10	NJT	0.03	-0.81	*1.4*	*2.8*	*1.7*	*0.04*	*0.07*
Correlation coefficient (ρ)			-0.25	*0.50*	*0.14*	*-0.49*	*0.59*	*-0.2*

** Correlation is significant at the 0.01 level ($p < 0.01$).

6.3.3 Qualitative "open-ended" descriptions of water sounds

Results obtained from sound categorisation (waterfall vs. fountain vs. stream) can be explained further by examining data obtained from qualitative description. At the end of the semantic differential test, participants were asked to answer the open-ended question "*If the sound evokes anything to you, please explain what it makes you think of*" (Appendix D) after listening to each water sound as many times as they wanted (as illustrated in section 6.2). All the answers are available in Appendix F.

In Table 6.7, a qualitative description of each water features considered is given as those most commonly mentioned (refer to Appendix F for details). These descriptions confirmed findings previously discussed in terms of natural streams (ST and CA) (section 6.3), manmade sounds (NJT, LJT and FF) (section 6.4.1), rainfall (SHW and DF) and waterfall (PEW) (section 6.4.2).

Results showed that water sounds (ST and CA) assigned to perceived category 3 (*natural stream*) were evocative of natural sounds: the cascade with four steps (CA) was associated to natural sounds from a river or a slow stream; the natural shallow stream

(ST) was described as resembling a small stream/river or water sounds from a botanic garden.

Furthermore, the large jet (LJT) was evocative of manmade sounds such as water dripping from a tap or falling into a container/tank or a water squirt machine used in restaurants. A similar trend was observed for the narrow jet (NJT) which reminded participants of artificial sounds played in restaurants as well as water filling up a pond/bath tub/container. The foam fountain (FF) reminded participants of a manmade movement of water, water in a tube or water coming out from a hole.

In the case of sounds from the waterfall made with small holes (SHW), these were identified as sounds resembling heavy rainfall or water on concrete; similarly, the dome fountain (DF) was evocative of rainfall and in some cases resembled overflowing roof drains and cold winter. Additionally, it can be noted that the sawtooth edge waterfall (SEW) was described as containing multiple sources: this was indeed made of multiple streams, i.e., multiple impact/areas/sources.

Furthermore, the remaining water features included in the list (PEW and FTW) were assigned to category 4 (*none of these*), as participants were not able to identify them (see section 6.3). Sounds from the plain edge waterfall (PEW) were qualitative

Table 6.7 Qualitative "open-ended" descriptions of water sounds in the presence of road traffic noise (refer to Table 3.1 for the definitions of acronyms). The qualities listed correspond to those most commonly mentioned.

Sound code	Qualitative description of the sound	% of selection
PEW	Waterfall, Rainfall	71.0
SEW	Multiple sources (water and noise)	33.3
SHW	Rainfall	66.7
FTW	Water feature in courtyard	30.7
DF	Rainfall	71.4
FF	Washing, manmade sound	60.0
LJT	Tap, manmade sound	75.0
NJT	Tap, manmade sound	66.7
CA	Natural stream	50.0
ST	Natural stream	50.0

described as a waterfall's sound or multiple sources' sounds (wind and rain/cars), while the fountain with multi-upward jets (FTW) was evocative of a courtyard's water feature for some participants. This was currently mentioned by Middle Eastern participants who are familiar with courtyard architecture including water features, suggesting that cultural factor might affect the evocation of water sounds.

Overall, it can be noted that water sounds evocative of natural sounds such as ST and CA were easily categorised by participants and tended to be preferred in the audio-only tests. On the contrary, water sounds resembling manmade features, such as the single upward jets (NJT and LJT), were not easily categorised but were perceived as manmade sounds evocative of water tap sounds, and tended not to be preferred on average.

6.3.4 Discussion

Results indicated that it is difficult to find a unique relationship between manmade water sounds as well as rainfall evocation and audio-only preferences. Fountains made with single jets were evocative of manmade water features and tended not to be preferred in the audio-only tests. On the contrary, waterfalls made participants think of natural features but they were poorly rated in the audio-only tests. A clear connection between evocation and sound preference was however found for the natural shallow stream (ST) and cascade (CA). These were rated as preferred water features, and were also evocative of natural sounds.

Single upward jets (NJT and LJT) were perceived as manmade sounds evocative of water tap sounds. These sounds tended not to be preferred in the audio-only condition: a negative correlation was found between manmade evocation and audio-only preferences, although this correlation was not significant. The same trend was observed between rainfall evocation and preferences: water sounds evocative of rainfall tended to be not preferred in the audio-only test, but the correlation was not significant.

6.4 Visual categorisation (manmade vs. natural)

The analysis of visual categorisation made for the water features tested aimed at evaluating the impact of different water features' displays on visual-only and audio-visual preferences, as well as on the qualitative characterisation of the corresponding water sounds. This test was carried out through an online test (see section 6.2 for details) in view of understanding whether the water features' displays appeared natural or manmade. Each subject was asked to answer to the question "*Indicate which type of* *water feature this image makes you think of*' by expressing their preference as *natural*, *manmade* or *neither* for each of the ten images visualised (refer to Appendix E for details).

6.4.1 Results

Figure 6.3 shows the results in terms of percentage obtained from the visual categorisation for the ten waterscapes examined in this study. Results indicated that the most naturally looking water features was the natural shallow stream (ST), followed by the small holes' edge waterfall (SHW) and the plain edge waterfall (PEW). All the other water features (FTW, SEW, NJT, DF, FF, CA and LJT) were visually associated to manmade structures by a majority of participants, with percentage above 70 % obtained for FF, FTW, NJT and SEW.

Additional analysis showed no correlations (Spearman test, $p < 0.05$) between the visual categorisation and the visual-only and audio-visual preferences, although all correlations between preferences and natural scores were positive, while all correlations between preferences and manmade score were negative.

This analysis provided a further insight into the audio-visual interaction of perception of waterscapes previously illustrated in Chapter 4, as the results justify the increase in

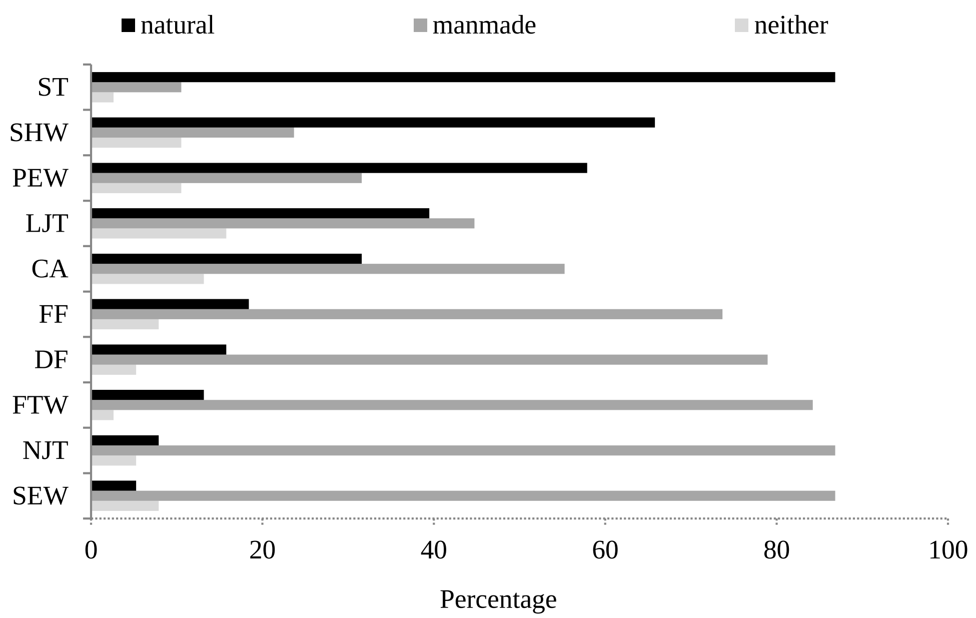


Figure 6.3 Visual categorisation (manmade vs. natural) of the ten water features tested (refer to Table 3.1 for definitions of acronyms).

audio-visual preference scores (compared to audio-only scores) found for ST, SHW and PEW (see to section 4.3.3 for details). Natural looking features tended to affect perception positively, although a manmade looking feature such as the cascade (CA) also improved perception (i.e., manmade looking features can be visually pleasing). Furthermore, on average, displays of the water features classified as manmade looking (SEW, NJT, DF, FF and LJT) tended to have a negative effect on perception in audio-visual conditions.

Although no significant correlations were found between visual categorisation and preferences of water features, results suggested that visual categorisation (manmade vs. natural) can affect the perception of waterscapes, as the displays that tended to be associated to a natural looking feature are those for which preferences improved in bi-modal sensorial conditions in most cases.

6.4.2 Discussion

Results from visual categorisation (manmade vs. natural) of displays of the ten water features tested showed that the displays of the water feature of ST, SHW and PEW were defined as natural looking (three out of ten water features). On the contrary, the remaining water features (FTW, SEW, NJT, DF, FF, CA and LJT) were visually classified as manmade looking. Moreover, these results provided a further insight into the audio-visual interaction of waterscapes. It was found that the more the visual settings were associated to natural water features (ST, SHW and PEW), the more they had a positive impact on audio-visual perception in view of improving relaxation in the presence of road traffic noise. This means that preference scores in audio-visual tests for ST, SHW and PEW increased as water features' displays were added to the sound stimuli. However, an exception was observed for the cascade with four steps (CA), which was rated as manmade but improved preferences as the visual stimulus was presented with the corresponding sound (i.e., manmade looking features can be visually pleasing). On the other hand, preference scores decreased with the presentation of the visual displays in the case of SEW, FF, DF, LJT and (marginally) NJT: these water features were visually classified as manmade structures. These findings reveal that visual categorisation might play an important role on the perception of waterscapes. However, further research would be needed to investigate the significance of the role of visual categorisation in driving preferences.

6.5 Conclusions

The sound categorisation (waterfall vs. fountain vs. stream) of the water features tested showed that the natural shallow stream (ST) and the cascade with four steps (CA) tend to be easily recognised and preferred in the audio-only tests, as a positive correlation was statistically significant between preferences and perceived category 3 (*natural stream*). On the contrary, water sounds resembling waterfalls and fountains with single jets were not easily identified, although waterfalls tended to be more identifiable than fountains. Additionally, no correlations were observed between audio-only preferences and scores obtained for both the perceived waterfall and perceived fountain categories. In general, natural streams were easily identifiable, unlike waterfall and fountain sounds.

Results obtained from the evocation of manmade water features and rainfall showed no unique relationship with sound preferences. Single upward jets (LJT and NJT) were perceived by most participants as manmade sounds evocative of water taps, and these tended not to be preferred (negative correlation with audio-only preferences), but the correlation was not statistically significant. A significant correlation was found between manmade sound evocation and roughness, whilst no clear relationship was found between acoustic/psychoacoustic parameters and rainfall evocation. Four out of ten water features were evocative of rainfall (SHW, DF, PEW and FTW). Furthermore, the correlation between rainfall evocation and audio-only preferences was negative, but not statistically significant.

The evocation of natural sounds did not always correspond to water features highly rated in the audio-only test, as in the case of the plain edge waterfall (PEW). This sound resembled natural features and was associated to rainfall evocation. The negative correlation with rainfall evocation might justify low ratings in terms of sounds preferences, although this correlation was not significant. Overall, results suggested that evocation might be strictly associated to the type of water features tested rather than to preferences.

The visual categorisation (natural vs. manmade) provided a further insight into the impact of audio-visual interaction on waterscapes’ perception. It was pointed out that water features’ displays associated to the natural shallow stream (ST) and the waterfalls with a small holes’ edge and a plain edge (SHW and PEW) were defined as natural looking structures, and these tended to increase audio-visual preference scores compared to audio-only preferences (although the mean differences were statistically significant only for ST, as pointed in section 4.3.3). On the contrary, manmade features tended to decrease audio-visual preferences compared to audio-only preferences. This means that visual settings associated to natural water features tended to have a positive impact on sound perception promoting peacefulness and relaxation in the presence of road traffic noise, although the exception represented by the manmade looking cascade (CA) suggests that well designed artificial features can be visually pleasing. However, correlations between the visual categorisation and visual-only as well as audio-visual preferences were not significant.

CHAPTER 7

Sound Maps of Water Features used over Road Traffic Noise

7.1 Introduction

This chapter focuses on the analysis of sound maps of water features in view of evaluating the sound pressure level effectiveness of these structures used over different ranges of road traffic noise levels, within the context of relaxation; as well as identifying the optimal distances where relaxation can be promoted (objectives 6 and 7, as shown in section 1.3 of Chapter 1). At the beginning, a brief description of the background relevant to this part of the work is given in order to identify the gaps in the current literature related to the water features' design considering different approaches (landscape architecture, engineering and acoustic approaches). Justifications of the work and the methodology used are then illustrated. In order to design sound maps for the water features tested, sound propagation models are explained for each type of sound source considered (point or line). Results are then presented in terms of sound maps developed over a 20 m × 20 m area for all the waterscapes tested in the audio-visual tests, as shown in Chapter 4. In addition, results of sound maps are also illustrated for all the different types of water features tested with different flow rates. Sound maps for water features used over road traffic noise are then presented in order to identify three acoustic zones ('water sound dominant zone', 'optimum zone' and 'road traffic noise dominant zone') around the water features. In these maps, results are illustrated in terms of optimal distance from the water feature where relaxation can be achieved in the presence of different levels of road traffic noise. In view of evaluating how the 'optimum zone' extends by varying the flow rate, results of sound maps for water features operating under different flow rates and used over different RTN levels are also included in this chapter. Moreover, results of sound maps for multiple (identical) water features located in different positions in the grid considered are illustrated, as well as sound maps for combinations of different water features used over road traffic noise. Additionally, a critical discussion is given at the end of each section, and conclusions are illustrated at the end of chapter.

7.2 Background

Water features have typically been categorised and designed in view of criteria such as visual and aesthetic appeals, settings and available space. In landscape architecture, designers have always taken into account the central visual aesthetic aspect of water features (Booth, 1989), although non-visual qualities of water have been recognised as important (Burmil *et al.,* 1999). For a landscape-architect, the larger emphasis placed on visual design has often relegated the auditory space to a domain generally accessed only through the channels of acoustic post-design consulting (Fowler, 2013). Booth (1989) provided a theoretical approach to basic elements of landscape design including water features, where a brief description of water generated sounds was given. However, these considerations were only limited to sound effects as a product of the visual design and were based on a qualitative description (e.g. a soft “hiss” emitted by a spray or a distinct dripping one made sound from a single orifice).

From an engineering viewpoint, the main factors affecting water features’ design depend mainly on the type of installation, the type of displays and features components (basin and reservoirs, pumps, plants space and location, distribution system as nozzles, valves and floor drains). General recommendations on sound characteristics of different fountain displays are identified and suggested by the CISBE Guide G (2004). Although these noise characteristics should be taken into account by designers, it is worth to note that these are related only to noise levels (very low noise level to very high noise level, as shown in Table 2.3 of Chapter 2), showing again a limited consideration given to the acoustic design of water features.

Acoustic criteria do not always appear to have figured in water features’ design and this failure can presumably be attributed to a lack of knowledge of how to predict and plan the effectiveness of acoustic masking in any particular setting, as pointed out by Brown and Rutherford (1994). A lack of basic research on auditory masking properties of positive sounds (e.g. water sounds) over annoying noise sources (e.g. road traffic noise) was also pointed out in a recent study by Nilsson *et al.* (2010). For that reason, a new concept of water features design can be considered using the soundscape approach by which acoustical and non-acoustical features are related to the subjective perception of sounds. In soundscape research, several efforts have been made to evaluate water sounds over road traffic noise, but only few recent studies have meticulously examined the perceptual assessment as well as the acoustical characterisation of water features used in outdoor spaces affected by road traffic noise, with the aim of improving soundscape perception (Watts *et al.*, 2009) (You *et al.*, 2010) (Jeon *et al.*, 2010) (Nilsson *et al.*, 2010) (De Coensel *et al.*, 2011) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013)

Table 7.1 Characteristic percentile levels in two city settings (Brown and Rutherford, 1994).

	Roadside setting (dBA)	Mall setting (dBA)
Peaks (L_{01})	80 + (vehicle passby)	70 + (voices, footsteps)
Median level (L_{50})	70	65
Background level (L_{90})	67 (adjacent bulk flow traffic noise)	64 (distant traffic, ventilation, people)

(Radsten-Ekman *et al.*, 2013) (Hong and Jeon, 2013). Among natural and artificial sounds, the sound of water has been often recognised as the preferred sound in an urban environment as well as the best sound used for enhancing soundscape perception (Jeon et al., 2010) (Kang, 2007). Studies have shown that the masking effect of water sounds is effective at mid-frequencies but not at low frequencies (Watts et al., 2009) (Galbrun and Ali, 2013), although tranquillity can also be improved for low level of masking (Watts et al., 2009).

Brown and Rutherford (1994) investigated the masking characteristics of a wide variety of water structures (waterfalls, fountain jets and cascades) over road traffic noise in city areas, and this work is described in some details below, due to the its relevance in relation to the results presented in this chapter. Partial masking can occur by reducing the loudness of city noises even where the level of water sounds is below (quieter than) the city noises (Brown and Rutherford, 1994). Based on the acoustic characteristics (the percentile levels L_{01}, L_{50} and L_{90}) of two city noise settings (roadside and mall settings), three acoustic zones ('zone of detection', 'zone of influence' and 'zone of exclusion') were identified as the areas where the effect of water structures is characterised by different levels of masking of urban noises (Table 7.1). In the zone of influence and exclusion, city noises can be partially or totally masked by water sounds. The zone of detection is the area in which city noises are dominant but the water structure can still attract attention acoustically (Brown and Rutherford, 1994). Predictions of sound levels were carried out for water structures such as a jet fountain, a waterfall and a linear water structure, by using a radiation model for each different sound source (point or line), as shown in Figure 7.1. The estimations were made using the sound level measured at one distance from each water structure. By considering the water sounds levels provided in Table 7.2 (no precise boundaries were defined between different masking zones), it was found that the zone of influence for a fountain with multiple large geysers (2 m high, 20 l/sec flow rate, concrete basin of 18 m × 7 m dimensions) located on the edge of a park was an area restricted

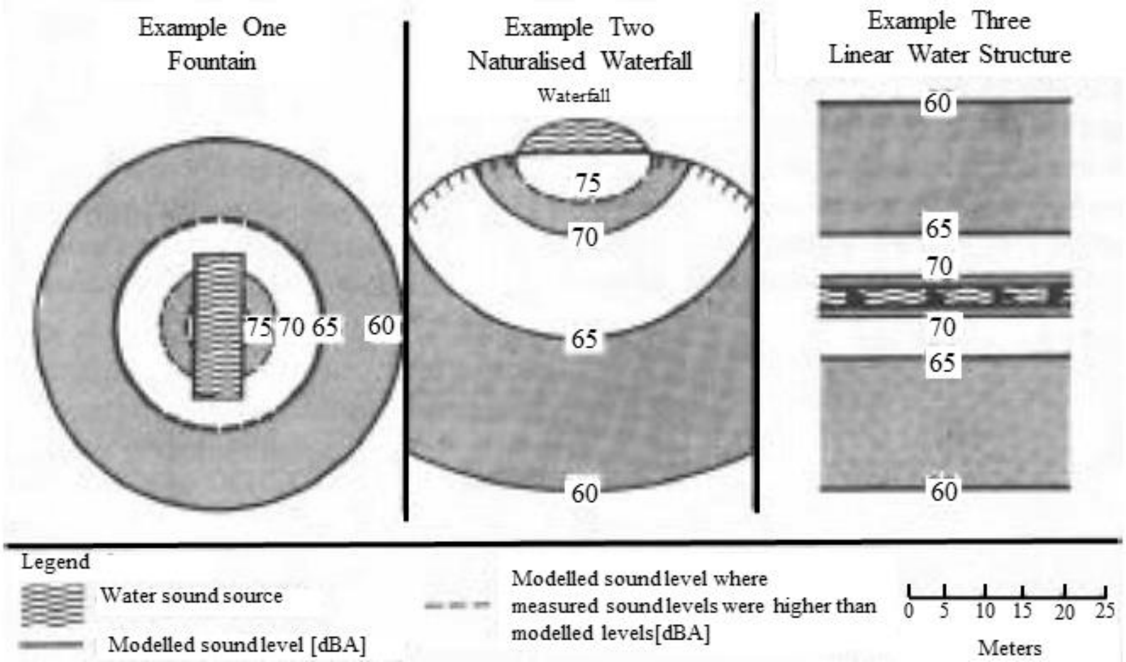


Figure 7.1 Prediction of water sound levels from point to line water structures (Brown and Rutherford, 1994).

Table 7.2 Water-generated sound levels (dBA) which would place an observer in a particular zone of masking in the different city settings (Brown and Rutherford, 1994).

		Water sound levels (dBA)	
Acoustic zone	**Definition**	**Roadside setting**	**Mall setting**
Zone of Detection	Dominant city noises Water sounds can still be detected	> 60	> 55
Zone of Influence	Partial masking of city noises Pleasant area where water sounds has softened urban noises and is used by people for relaxing	70-80	65-70
Zone of Exclusion	Dominant water sounds	≥ 85	≥ 75

between 5 to 10 metres from the fountain. For a naturalised waterfall (6 m high and 11 m wide, 125 l/sec flow rate) made by boulders and natural vegetation and located in an inner city park, the zone of influence extended to 25-30 m from the base of the water structure. For a linear water structure consisting of a low volume but continuous flow of water dropping down a series of 20 steps, the zone of influence was restricted to 5 meter for a roadside setting. The definition of different acoustic zones, suggested by Brown and

Rutherford (1994) is conceptually interesting. However, it is worth noting that this evaluation was merely made according to noise levels of road traffic noise measured in only two acoustic settings (e.g. in zone of influence, water sounds levels are ranging between the median level, L_{50} and the peak level L_{01} of road traffic noise measured in that specific setting). In addition, the assumptions for defining the acoustic zones are only based on theoretical considerations of auditory masking properties which were not confirmed by experimental tests (e.g. listening tests used for assessing the loudness of masker sounds (water sounds) and target sounds (road traffic noise)).

Boubezari and Coelho (2004) indicated a need to develop qualitative sound maps in view of identifying the soundscape composition of an environment. The authors developed audibility maps of water sounds generated from a large fountain located in an urban square. The audibility maps consisted of curves for which the corresponding values did not indicate the acoustic level of the sound source but the level of the pink noise necessary to mask the sound source. Sound maps for the fountain sounds indicated that water sounds were dominant in a region close to the fountain, but were not audible in the area where road traffic noise was dominant.

Furthermore, in a recent study on the use of water sounds for masking road traffic noise, Nilsson *et al.* (2010) carried out listening tests in order to assess the loudness of road traffic noise and water sounds from a large jet-and-basin fountain. The water feature (21 m x 14.5 m) consisted of three large jets and two smaller nozzles mounted on a group of three bronze statues and was located in the middle of an urban park (130 m x 60 m), about 50 m from a main road (generating sound levels of 65 dBA at 1 m from the fountain). A positive effect of water sounds on improving the soundscape perception was found in a region 20-30 m around the water structure where the fountain sound was equally loud or louder than the road traffic noise (Nilsson *et al.*, 2010). However, this analysis was limited to a single type of water feature such as a large fountain jet, and water sounds' quality was evaluated with respect only to the perceived loudness of sounds. Moreover, Axelsson *et al.* (2014) investigated the impact of sounds from a jet-and-basin fountain (same water structure used by Nilsson *et al.* (2010)) on soundscape quality in an urban park. Results showed that people dislike road traffic noise and natural sounds tend to be preferred. It was found that this effect is unrelated to sound pressure levels, meaning that natural sounds are preferred to road traffic noises also when the sound pressure levels are equal. Additionally, the fountain had a positive effect on improving soundscape perception in a zone close to the feature but this was restricted to approximately 10 m from the structure compared to the region identified by Nilsson *et al.* (2010) (Axelsson *et al.*, 2014).

7.3 Justification of the work and methodology

Several efforts have been made to investigate the acoustic use of water sounds over road traffic noise, but further research is needed to identify "harmonised" criteria for the design process of an acoustic environment where water sounds might be used for masking road traffic noise in different noise settings. It is already known that water sound levels can vary depending on the type and design of water features, but there is no knowledge about what type of water feature is most effective for masking a specific level of road traffic noise. Furthermore, a better knowledge is necessary to be able to integrate the soundscape design of water feature as a strategy for future urban planning and design. In this context, the aim of the work presented here is to fill this gap by evaluating the levels of relaxation that can be achieved in different areas around a water structure in the presence of road traffic noise. This evaluation has been made for a wide variety of small to medium sized water features (waterfall, fountains, cascade and streams) by comparing sounds levels between water sounds and road traffic noise. Predictions of sound pressure levels for different water features were made by using sound propagation models based on the type of sources (point or line) and presented in terms of sound maps. The predicted sound levels were then used to define acoustic areas with different levels of relaxation for each type of water structure tested.

The concept of different acoustic zones around water structures used over road traffic noise was introduced according to the idea suggested by Brown and Rutherford (1994). However, this concept has been expanded by taking in account quantitative criteria based on results pointed out by previous research and obtained in terms of water features' perception. The criteria used for the definition of the acoustic zones are:

- The preferred noise level of water sounds should be similar or not less than 3 dB below the road traffic noise in order to improve the soundscape perception *(*You *et al.*, 2010) (Jeon *et al.*, 2012), and this was also identified as the preferred level in the context of relaxation (Galbrun and Ali, 2013).
- A positive effect in improving soundscape perception can occur in a region around the water structure where the fountain sound was similar or below (quieter than) the road traffic noise (Nilsson *et al.*, 2010) (Axelsson *et al.*, 2014).

Table 7.3 Definitions of three acoustic zones around water features used over road traffic noise (RTN). The zones are based on sound pressure levels (dBA).

Acoustic zone	Definition*	Water sound levels (dBA)
RTN dominant zone	Water sounds lower than RTN	< RTN - 3 dB
Optimum zone	Water sounds similar or less than RTN Improvement of soundscape perception Relaxation can be achieved	[RTN - 3 dB, RTN]
Water sound dominant	Water sounds louder than RTN	> RTN

*No precise boundaries for areas where relaxation can occur.

Three acoustic zones ('water sounds dominant zone', 'optimum zone' and 'RTN dominant zone') were identified for waterscapes located in different noise settings defined by sound pressure levels. In the 'water sound dominant zone', water sounds are louder than road traffic noise (RTN) (Table 7.3). In this area people can be attracted by water sounds, but road traffic noise can still be audible. In the 'optimum zone', water sound levels are similar or not less than 3 dB below road traffic noise (RTN) (Table 7.3). This is an area where soundscape perception can be improved by water sounds and relaxation/pleasantness can be achieved. The 'RTN dominant zone' is defined here as the area where water sounds levels are lower than the RTN level minus 3 dB (Table 7.3): road traffic noise is the principal noise source, but water sounds can still be detected. This analysis does not consider relaxation occurring just in a specific area with precise boundaries. It assumes that relaxation can also be achieved outside the 'optimum zone', as tranquillity can still be improved for low levels of masking (Watts *et al.*, 2009) (e.g. in areas where water sounds are lower than RTN). Furthermore, this analysis was made for all the water features tested in the laboratory (as described in Chapter 4) by taking into account audio-visual preferences. This was done in order to evaluate which type of water feature is most effective in promoting relaxation, as well as to identify the optimal distances from the water feature where relaxation can be achieved. This allowed revealing evidence-based solutions for the design of individual or combined water features which can be located in specific road traffic noise settings in view of improving relaxation and peacefulness.

7.4 Models for predicting sound pressure levels at receivers

In order to design sound maps for the water features tested, sound propagation models were used for each type of sound source considered (point or line). A prediction of sound pressure levels at different receiver positions was made by considering each water feature located in a grid of 20 m × 20 m, and the road responsible for road traffic noise was positioned distant enough from the garden/park, so that variations in sound pressure level across the 20 m x 20 m grid were negligible (e.g. below 2 dB) (Figure 7.2). This allowed assuming that the RTN level was constant across the grid considered. The receiver height was set to 1.2 m above the ground, as representative of a person seated in a garden or park from which she/he can hear and see a water feature in the presence of road traffic noise. Calculations were made for a grid point spacing of 1 m, assuming an ideal case scenario where sound is propagating in a semi-free field environment from a sound source placed on the ground (no reflecting surfaces along the propagation path, i.e. barriers or obstacles, with the exception of the ground surface). The propagation models include input data defining the sound power level of each water feature as well the directivity correction, and data related to attenuations due to geometrical divergence, atmospheric absorption and ground effect. Details of the models used are given in the following sections, including the definition of sources, the calculation of sound power levels, and the models for point and line sources.

7.4.1 Definitions of sound sources

Water features tested in the audio-visual tests included waterfalls, cascades, fountains with upward jets and a natural stream (details are given in Table 3.1). All water features

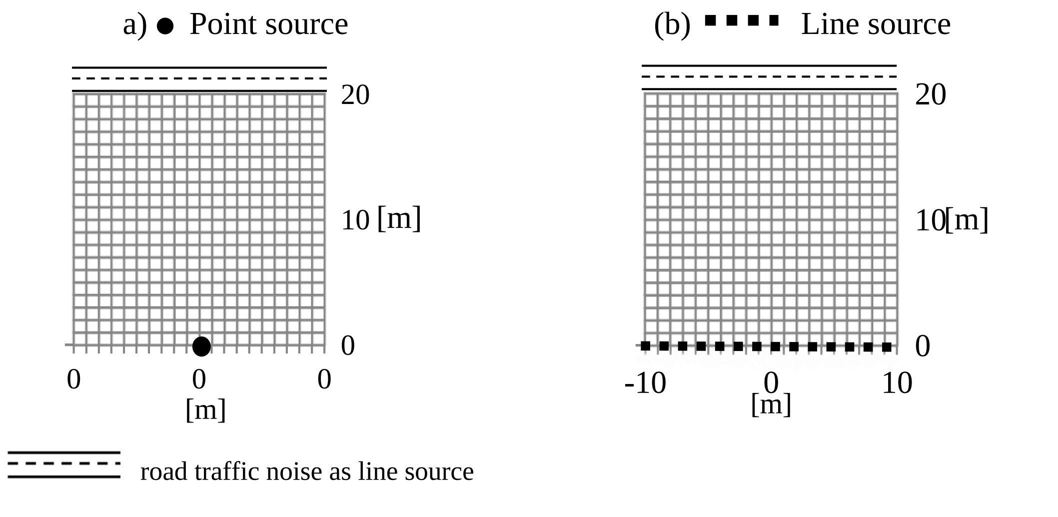


Figure 7.2 Calculation grid of 20 m × 20 m and location of sound sources: (a) point source and (b) line source.

were modelled as emitted from point sound sources, with the exception of the natural stream which was studied as a line sound source as well as a multiple points source. Based on the Rathe method (Smith *et al.*, 1997), the waterfalls and cascade were considered to behave as point sound sources. According to this method, a planar finite source of height *a* and length *b,* radiates a sound pressure level that remains more or less constant close to the sound source ($r < a/\pi$) (refer to Figure 3.2 of Chapter 3). At large distances (relative to the dimensions of the sources), the wavefronts become spherical and thus the sound pressure level falls at 6 dB per doubling of distance ($r > b/\pi$). In between these two situations, there is a region where the reduction may approximate to the 3 dB decrease per doubling of distance of a line source (Smith et al., 1997). Based on this, at a distance beyond $1/\pi = 0.32$ m for 1 m wide waterfalls as well as $0.25/\pi = 0.08$ m for the 0.25 m wide cascade (dimensions tested in this research), the sound pressure levels reduce at a rate of 6 dB per doubling of distance, i.e. the features behave as a point source Therefore, the waterfalls (b = 1 m) and cascades (b = 0.25 m) were considered as point sources in the work presented here, as receiver distances were always greater than 1 m. In the next section, details of calculations of sound power levels for all the water features tested are given.

7.4.2 Calculation of sound power levels

The sound power level, L_w, of water features was estimated by using the classical acoustic equation (7.1).

$$L_w = L_p + 10\log S \qquad \text{(dB re } 10^{-12} \qquad (7.1)$$

where L_p is the sound pressure level expressed in dB and S is the surface through which sound propagates at a distance r. Measured values of L_p used for this prediction were available from previous research (Galbrun and Ali, 2013). Galbrun and Ali (2013) carried out laboratory measurements for all the water features tested at a distance of 0.5 m from the center section of the sump tank (impact area of falling water) and 1 m above floor level (refer to Figure 3.2 in Chapter 3 for details). This receiver position was chosen as representative of a person seated in the vicinity of a water feature (1.2 m above the water level), whilst still being largely dominated by the direct field (i.e. negligible influence from the reverberant field of the large laboratory) (Galbrun and Ali, 2013). The exception was represented by the natural stream for which measurements were carried out in the field at a distance of 2 m from the junction of two streams and 1 m above the ground. In the work presented here, L_w of the water features tested in the laboratory was calculated assuming a point source radiating over a hemi-sphere ($S = 2\pi r^2$), where r is the distance from the sound source considered. The prediction of L_w was made at the distance r = 1.3 m from the point sound sources (Figure 3.2, Chapter 3) for all water features tested in the laboratory. With regard to the natural stream, calculations of L_w were made assuming an ideal line source of infinite length located close to the ground and radiating sound over a hemi-cylinder ($S = \pi r$, for a 1 m section), at a distance r of 2.2 m. In this case, L_w is expressed in dB/m re 10^{-12} W.

7.4.3 Propagation model for point source

Calculations of the equivalent continuous downwind octave-band sound pressure level at a receiver location, $L_{fT}(DW)$, were made for each point sound source for the eight octave bands with nominal midband frequencies from 63 Hz to 8 kHz according to the procedure of ISO 9613 (Part 1:1993, Part 2: 1996). The equation for $L_{fT}(DW)$ is:

$$L_{fT}(DW) = L_w + D_c - A \qquad \text{(dB)} \qquad (7.2)$$

where L_w (dB re 10^{-12}W) is the octave-band sound power level produced by the sound source relative to a reference sound of one picowatt (1 pW=10^{-12} W) (as described in section *7.4.2*); D_c (dB) is the directivity correction; and A (dB) is the octave-band attenuation that occurs during propagation from the point sound source to the receiver. The attenuation A (dB) can be found from:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad \text{(dB)} \qquad (7.3)$$

where A_{div} is the attenuation due to geometrical divergence (dB), A_{atm} is the attenuation due to atmospheric absorption (dB), A_{gr} is the attenuation due to the ground effect (dB), A_{bar} is the attenuation due to the presence of barriers (dB) and A_{misc} is the attenuation due to other miscellaneous effects (dB).

The equivalent continuous A-weighted sound pressure level in downwind conditions can be found by summing the contributing time-mean-square sound pressures calculated according to equation (7.2) and (7.3) for each point sound source and for each octave band, as specified by equation (7.4):

$$L_{AT}(DW) = 10\ \log\left\{\sum_{i=1}^{n}\left[\sum_{j=1}^{8} 10^{\left[L_{fT(ij)}+A_{f(j)}\right]/10}\right]\right\} \qquad \text{(dB)} \qquad (7.4)$$

where n is the number of contributions i (sources and/or paths), j is indicating the eight standard octave-band midband frequencies from 63 Hz to 8kHz, and A_f denotes the standard A-weighting (dB).

Directivity

The directivity correction, D_c, describes the extent by which the equivalent continuous sound pressure level from the point source deviates in a specified direction from the level of an omnidirectional sound source producing the sound power level L_w (ISO 9613-2, 1996). This is defined as the difference in decibels between the measured sound pressure level in a given direction (θ) from a real source and the sound pressure level from a notional omnidirectional source of the same power level (Long, 2006).

$$D_c = L_\theta - L_{av} \quad \text{(dB)} \tag{7.5}$$

where D_c is the directivity index for a given direction (dB), L_θ is the sound pressure level for a given direction (dB) and L_{av} is the sound pressure level averaged over all angles (dB). It can be also calculated from

$$D_c = 10 \log Q \quad \text{(dB)} \tag{7.6}$$

where Q is the directivity factor which expresses the ratio of the sound intensity, I, in a given direction measured at a certain distance from the source divided by the average sound intensity at the same distance (average taken over all angles). This is defined as

$$Q = \frac{I}{I_{av}} = \left(\frac{p}{p_{av}}\right)^2 \tag{7.7}$$

where I_{av} and p_{av} are the values obtained from an omni-directional source emitting the same sound power. The average intensity at a distance r (m) can be calculated from the sound source's power W (Watts) as

$$I_{av} = \frac{W}{4\pi r^2} \tag{7.8}$$

For an omni-directional source in the free field, $Q = 1$ and the equivalent $D_c = 0$ dB; for an omni-directional sound source placed above a reflecting surface (such as a ground surface in the case of the water features tested), $Q = 2$ and $D_c = 3$ dB.

Geometrical divergence

Attenuation due to the geometrical divergence accounts for spherical spreading in the free field from an omni-directional source (ISO 9613-2, 1996). It can be expressed in decibels by

$$A_{div} = \left[20\log\left(\frac{d}{d_0}\right) + 11\right] \quad \text{(dB)} \quad (7.9)$$

where d is the distance from the source to the receiver in meters and d_0 is the reference distance (1 m).

Atmospheric absorption

The attenuation due to the atmospheric absorption can be expressed in decibels and is a function of the propagation through a distance d (m) (ISO 9613-2, 1996).

$$A_{atm} = \frac{\alpha \cdot d}{1000} \quad \text{(dB)} \quad (7.10)$$

where α is the atmospheric attenuation coefficient (dB/km) for each octave band at the midband frequency. This attenuation depends on the frequency of the sound, the ambient temperature and relative humidity of air, but only weakly on the ambient pressure. Different values of α at atmospheric conditions can be found in ISO 9613-1 (Part1: 1993). In the results presented in this chapter, attenuation coefficients were considered for a temperature of 20°C and a relative humidity of 70% at a pressure of one standard atmosphere (101,325 kPa).

Ground effect

Ground attenuation is mainly the result of sound reflected by the ground surface interfering with the sound propagating directly from the source to the receiver (ISO 9613-2, 1996). Assuming that the sound propagation occurs over porous ground with vegetation (ground factor G close to 1), A_{gr} can be calculated as:

$$A_{gr} = 4.8 - \left(\frac{2h_m}{d}\right)\left[17 + \left(\frac{300}{d}\right)\right] \geq 0 \quad \text{(dB)} \quad (7.11)$$

where h_m is the mean height of the propagation path above the ground (m) and d is the distance from the source to the receiver (m). The mean height h_m can be evaluated by the method shown in Figure 7.3. Negative values for A_{gr} from equation (7.11) shall be replaced by zeros. When the ground attenuation is calculated by using equation (7.11), there is an apparent increase in sound power level of the source due to the reflections from the ground near the source. For that reason, an additional term D_{Ω} should be included when calculating the directivity correction D_c in equation (7.2).

$$D_{\Omega} = 10\log\left\{1 + \frac{\left[d_p^2 + (h_s - h_r)^2\right]}{\left[d_p^2 + (h_s + h_r)^2\right]}\right\} \quad \text{(dB)} \quad (7.12)$$

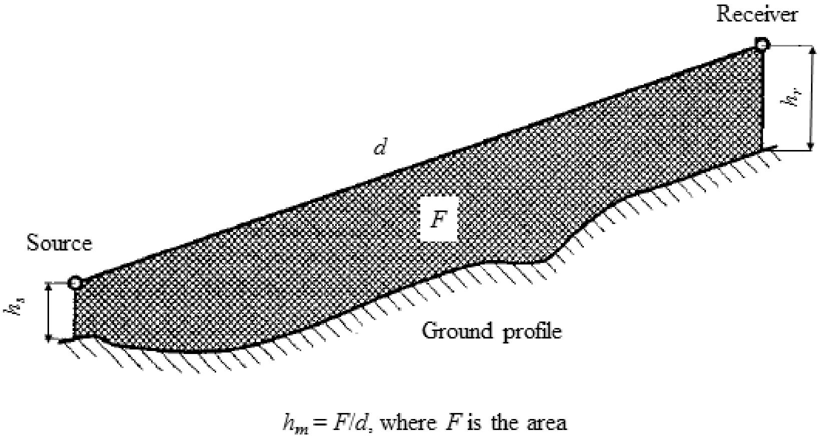


Figure 7.3 Method for calculating h_m (ISO 9613-2, 1996).

where h_s is the height of the source above the ground (m), h_r is the height of the receiver above the ground (m), and d_p is the source-to-receiver distance projected onto the ground plane (m) (ISO 9613-2, 1996). Assuming the absence of barriers and reflections, the attenuations A_{bar} and A_{misc} were ignored for the predictions presented in this work.

7.4.4 Propagation model for line source

In the case of the natural stream (the only feature studied as a line source), two different models were used to predict the sound pressure levels at a receiver by assuming either multiple points or a line source. However, the prediction of sound pressure levels requires specifying the strength of the source (sound power level, L_w). Because of the complexity related to the configuration of a natural stream (e.g. the most dominant sounds originate from the up and down motion of the water surface and is due to the impact of water striking over solid surfaces, such as boulders and stones), a simplified model was chosen for the calculation of sound power levels. The estimation of L_w was made assuming a line source of infinite length (referring to 1 m section) and taking into account the measured sound pressure level at a known distance from the source (as illustrated in section *7.4.2*) by using equation (7.13). Although calculations of L_w can be more accurate by using sound pressure levels determined from multiple point measurements, an ideal scenario was assumed where the sound is spreading uniformly along the baseline of the stream and calculations were simplified by considering sound pressure levels from a single point measurement.

$$L_w = L_p + 10\log(\pi r) \qquad \text{(dB/m re } 10^{-12}\text{ W)} \qquad (7.13)$$

Initially, the prediction of sound pressure levels at different receiver positions was made by using both the multiple points model of equation (7.2) and the line model of equation (7.14). Additionally, the calculated sound pressure levels obtained from equations (7.2) and (7.14) were compared with the measured levels obtained from measurements carried out in the field in order to verify the reliability of the two models.

Multiple points model

The propagation model provided by ISO 9613-2 (Part 1: 1996) predicts the sound pressure level at a receiver assuming point sources only (as described in section *7.4.3*). In the case of a line source, a common approach is to break the source down into line sections, each represented by a point source at its centre. Predictions of sound pressure level can then be treated by calculating the individual noise levels of each point source and adding the result logarithmically. According to ISO 9613-2 (Part 2: 1996), the assumptions to the model include that:

- ✓ Multiple point sources have approximately the same strength (sound power level) and height above the local ground plane;
- ✓ Multiple point sources are uncorrelated (i.e. not in phase);
- ✓ The same propagation conditions exist from the sources to the point of reception;
- ✓ The distance d from the single equivalent point source to the receiver exceeds twice the largest dimension H_{max} of the source ($d > 2H_{max}$).

A prediction of the sound pressure level at the receiver was made by using equation (7.2) and considering a group of closely spaced point sources along the line of the stream (34 points with a spacing of 1 m from each other), where values of L_w were based on equation (7.13).

Line source model

In order to estimate the sound pressure level at receiver in the far field, calculations were also made using a simple line source model by including the directivity index (D) and attenuations due to atmospheric absorption (as indicated in ISO 9613-1 (Part 1:1993)). The following classical acoustic equation relating power to sound pressure level for a line source was used:

$$L_p = L_w - (10logd + 8) + D_c - \alpha_t d \quad \text{(dB)} \qquad (7.14)$$

where L_w is the sound power level of the sound source (dB/m re 10^{-12} W) (equation (7.13)); $10\log d+8$ is a term that takes into account the geometrical divergence due to cylindrical spreading of sound where d is the distance from the source to the receiver (m); D_c is the directivity index, equal to 3 dB in the case of a line source radiating over a hemi-cylinder; α_t (dB/m) is the attenuation coefficient for atmospheric absorption at the exact midband frequency as shown in Table 1 of ISO 9613-1 (Part 1:1993). Calculations of L_p were made for the eight octave bands with nominal midband frequencies from 63 Hz to 8 kHz; and the equivalent continuous A-weighted sound pressure levels were then obtained by applying A-weighting corrections to all contributions for each octave band and summing them logarithmically. Attenuations by additional mechanisms such as barriers and reflections were excluded in this prediction. Finally, ground attenuation (A_{gr}) was not included in this model because the suggested values of A_{gr} were found to be negligible for the distances considered (1-20 m, source-receiver distance). From a review of the literature, calculations of A_{gr} referring to sound propagation from a line source can be only based on a prediction model according to Calculation of Railways Noise 1995 (UK Department of Transport, 1995). This model suggests values of ground corrections as a function of the horizontal distance (d) of the source line from the receiver point, the mean height (h_m) of propagation and the proportion of absorbing ground (ground factor, G). Assuming a sound propagation over porous ground with vegetation (ground factor G close to 1), the values of A_{gr} are equal to 0 dBA for a distance d between 0 and 50 m (UK Department of Transport, 1995). In addition, results based on the propagation model of ISO 9613-2 (Part 2: 1996) assuming a spherical propagation showed a ground correction of approximately 0 dBA for source-receiver distances between 0 and 15 m, and values of A_{gr} less of than 3 dBA for distances between 15 and 20 m. For that reason, ground attenuation was not included in this model.

In order to understand the accuracy of the two propagation models applied (equations (7.2) and (7.14)), some spot measurements were carried out in the field for a stream located in Edinburgh (Water of Leith, Redhall Walled Garden). Measurements of A-weighted sound pressure levels averaged over 20 s were undertaken at different positions along the perpendicular line from the source (stream) to the receiver (every 1 m up to 15 m away from the source) at a height of 1 m above the ground. The noise measurements were repeated twice in each measurement spot. With the help of the measured noise levels, a comparison with the calculated values of sound pressure levels obtained by using the models described above (equations (7.2) (Figure 7.4(a)) and

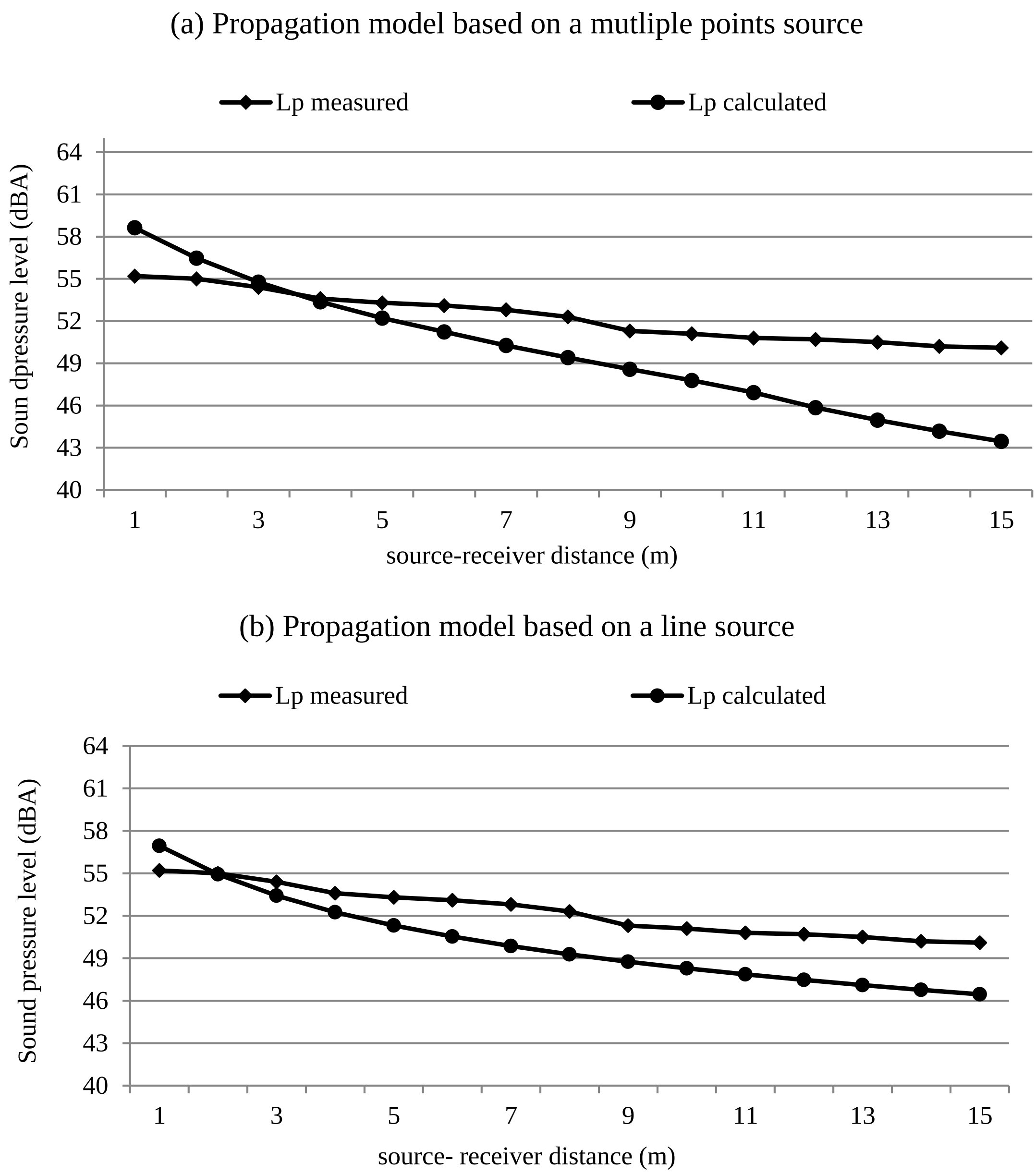


Figure 7.4 Propagation models based on a (a) mutliple points and (b) line source: a comparison between the calculated sound pressure levels using equations (7.2) and (7.14) and the sound pressure levels measured in the field (Water of Leith, Redhall Walled Garden, Edinburgh).

(7.14) (Figure 7.4(b)) was made. Results showed some discrepancies between the measured values in the field and the experimental results obtained using both models of propagation (line and mutliple points) (Figure 7.4). The calculated value of sound pressure levels were lower than those measured, and this was expected to have been caused by the presence of other sound sources during the measurements. Furthermore, it was found that the propagation model based on the line source formula (equation (7.14)) shows more reliable data predictions when compared to the actual values measured in the field (Figure 7.4(b)). For that reason, the predicted sound pressure levels for the natural stream presented in this chapter are based on the model of equation (7.14).

7.5 Results

Predictions of sound pressure levels (SPL) at the receiver were made for all the waterfeatures tested in the audio-visual tests. In this section, results are presented in terms of sound maps where water features are located in a grid of 20 m × 20 m. The size of this area was considered large enough for being representative of a setting where small to medium sized water features can be installed, such as gardens or some areas in parks. Sound pressure levels are expressed in the maps as dBA and displayed on a greyscale colour/pattern in which each shade of grey or pattern corresponds to a 5 dBA change in level (refer to Table 4.1 for acronyms and details about the water features). These maps are presented in the ranking order of preferences obtained from the audio-visual tests (Chapter 4). Finally, estimations of sound pressure levels were also examined for water features with different flow rates.

7.5.1 Sound maps of individual water features

Figures 7.5-7.6 illustrate sound maps of individual water features. Results showed that the natural stream (the only case tested in the field) generates levels of 49 dBA in proximity of the feature and 36 dBA at a distance of 20 m (Figure 7.5 (a)). A cascade with four steps (CA), a fountain with 37 upward jets (FTW), a dome (DF) and a foam (FF) fountains generated sound levels of around 61-66 dBA at the edge of the fountains and approximately 35-38 dBA at 20 m from these water structures (Figures 7.5 (b-f)). However, a small holes waterfall (SHW) produced slightly higher sound levels ranging between 43 to 68 dBA at distances of 20 m and 1 m respectively from the structure (Figure 7.5 (d)). Similarly, water sounds levels produced by a sawtooth edge waterfall (SEW), a plain edge waterfall (PEW), and a narrow jet (NJT), resulted in a range from 45 to 71 dBA at respectively 20 m and 1 m distance from the water structures (Figure 7.6 (a)-(c)-(d)). Finally, a large jet (LJT) produced lower sound levels ranging between 21 to 41 dBA at respectively 20 m and 1 m from the fountain (Figure 7.6 (b)).

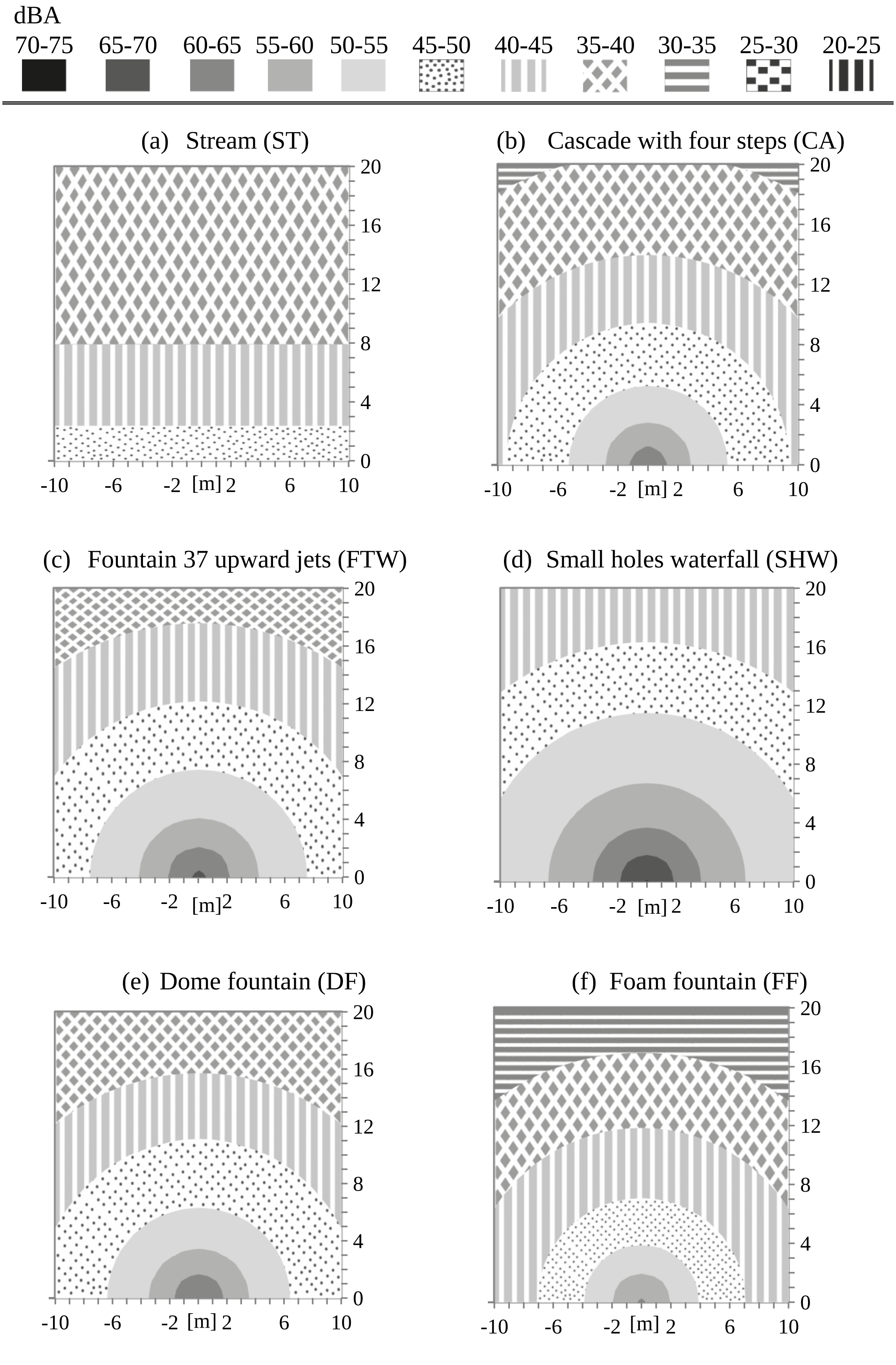


Figure 7.5 (a)-(f) Sound maps for ST, CA, FTW, SHW, DF and FF.

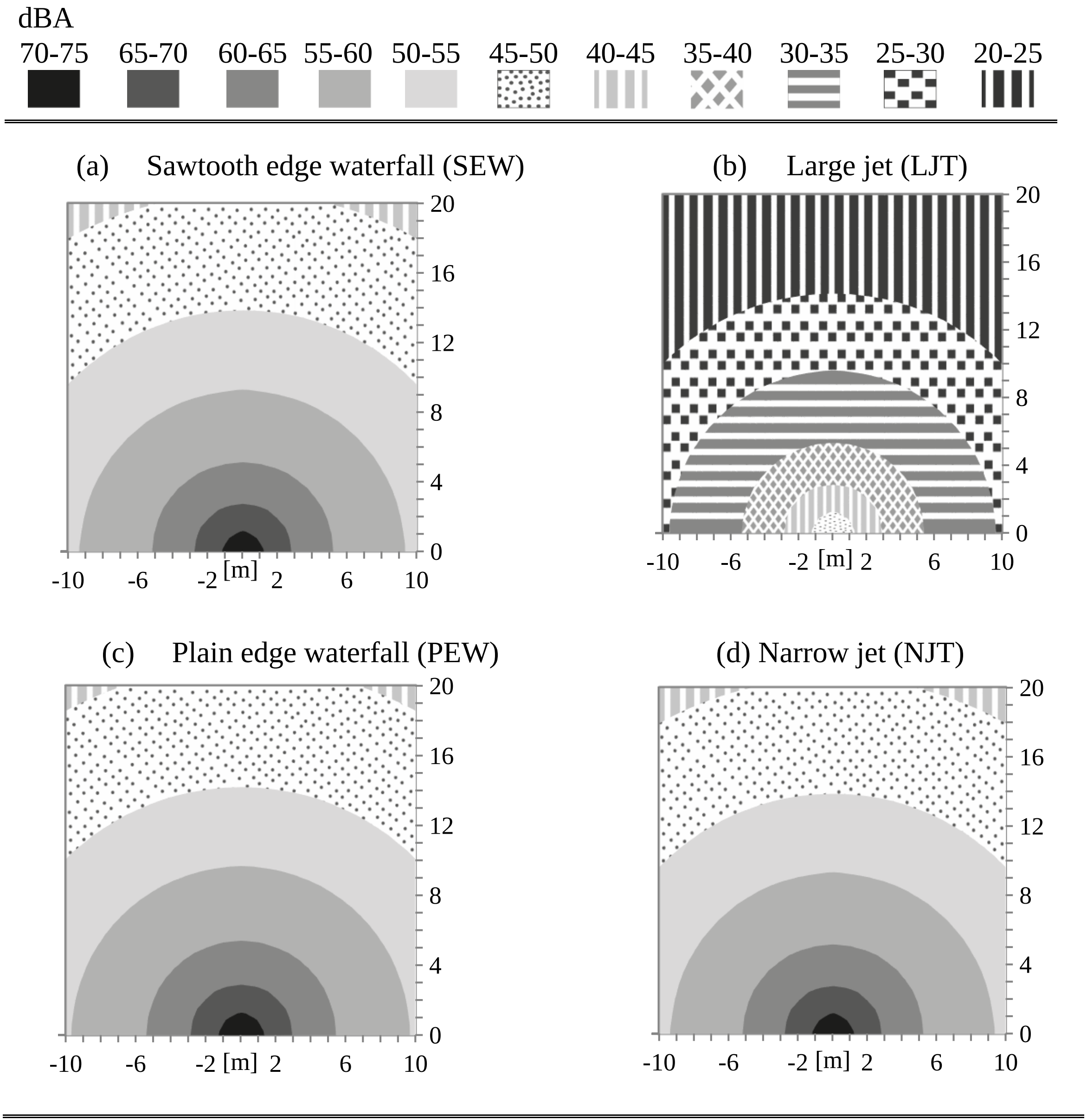


Figure 7.6 (a)-(d) Sound maps for SEW, LJT, PEW and NJT.

7.5.2 Sound maps vs. Flow rate

Predictions of sound pressure levels were also made for all the different types of water features tested with different flow rates. In this section, three examples are shown to illustrate the main findings. Figures 7.7-8 show the sound maps for a cascade with four steps (CA) (flow rate ranging from 5 to 60 l/min), a sawtooth edge waterfall (SEW) with a flow rate of 15 to 150 l/min, and a natural stream with a flow rate of 2400 and 4800 l/min (0.04 and 0.08 m^3/sec) respectively. It was found that, for the cascade, large variations in levels occur between low flows (5-15 l/min), whilst small variations can be observed between high flows (30-60 l/min) (Figure 7.7(a)). A similar trend was found for other types of fountains such as the large and narrow jets (LJT and NJT), whilst, in the case of the dome fountain (DF) and the fountain with upward jets (FTW), small

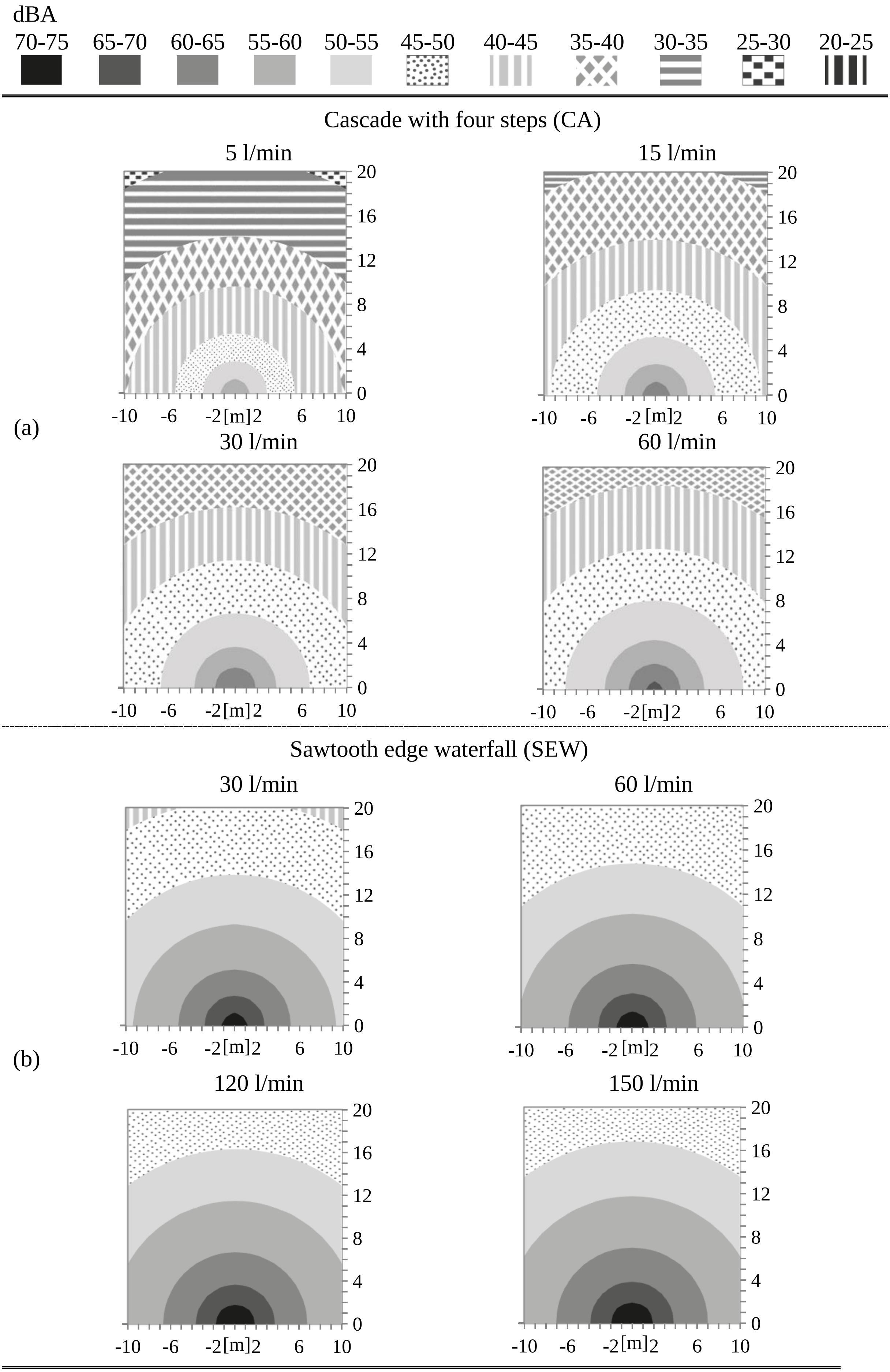


Figure 7.7 (a)-(b) Sound maps vs. Flow rates for CA and SEW.

variations were observed between low flows (20-25 l/min for DF; 5-15 l/min for FTW) and large variations between high flows (30-50 l/min for DF; 20-40 l/min for FTW). Furthermore, noticeable variations in levels (~ +8 dBA) were observed for a foam fountain (FF) by increasing its flow rate (30-45 l/min), while a small increase of the sound pressure levels was found for the small holes waterfall (SHW) when varying the flow of 15 to 30 l/min. Additionally, for the sawtooth edge waterfall (SEW), small variations in levels were found at both low (30-60 l/min) and high (120-150 l/min) flows, as shown in Figure 7.7(b). This trend was also confirmed for a plain edge waterfall, PEW, operating under low (30-60 l/min) and high (120-150 l/min) flows.

Finally, in Figure 7.8, sound maps vs. flow rates are given for two natural shallow streams with a flow of 2400 l/min and 4800 l/min. Results showed that sound pressure levels can increase of approximately 5 dBA when doubling the stream's flow (sound pressure levels ranging between 49-36 dBA at respectively 1-20 m from the stream with a flow of 2400 l/min, while a range of 54-42 dBA was found at respectively 1-20 m from the stream with a flow of 4800 l/min). Among the water features used in the audio-visual tests, the natural stream (ST) represents the only case tested in the field (Pentland Hills, South of Edinburgh) (Figure 7.9(a)). This stream shows shallow water flowing over stones (approximately 0.10 m depth of water). Measurements of sound pressure levels were carried out at the top edge of a junction (two streams merging), with one stream 2 m on the right, the other source stream 2 m on the left and the new stream 5 m in front and 1 m above water (as shown in Figure 7.9(a)) (Ali, 2012). In order to evaluate streams with different flow rates, a large amount of data available from

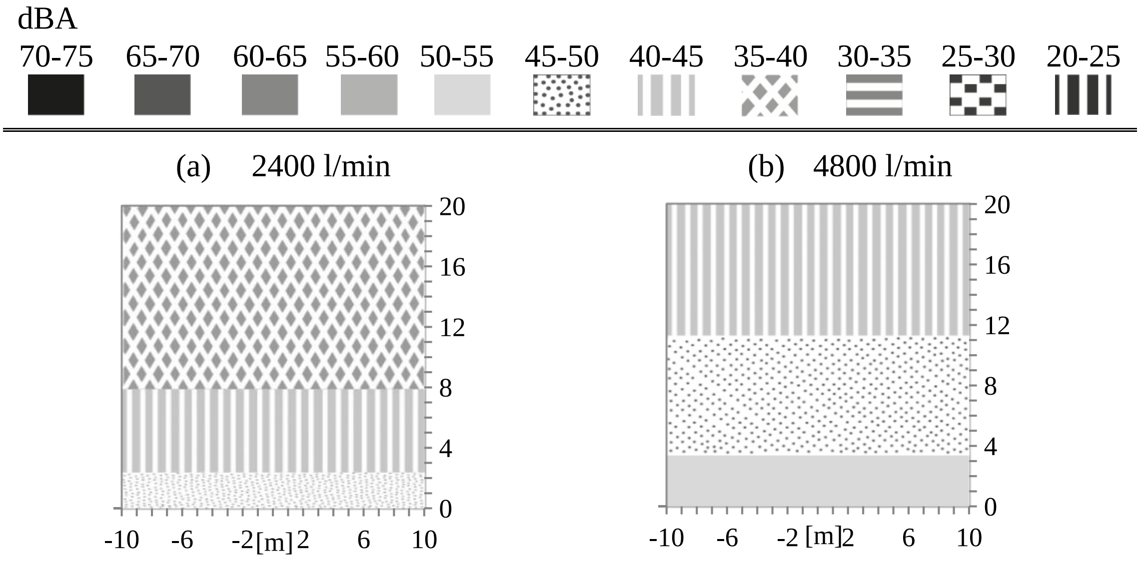


Figure 7.8 Sound maps vs. Flow rates of two natural streams (ST).

(a) Shallow stream (2400 l/min) (b) Shallow stream (4800 l/min)

Figure 7.9 (a)-(b) Two streams tested in the field (Edinburgh) (Ali, 2012).

previous research (Ali, 2012) was considered to identify another stream generating similar water sounds (sounds from shallow water flowing over stones) but producing higher sound pressure levels. The additional stream identified was similar in size and configuration to the one previously described (shallow depth of water flowing over stone), with a water width of 3 m and approximately 0.15 m depth, but with a higher number of stones lying on the stream bed (Figure 7.9(b)). For this stream, measurements of sound pressure levels were carried out 2.5 m perpendicular to the stream and 1.5 m above the water, as shown in Figure 7.9(b) (Ali, 2012).

Measurements of flow rates were carried out in the field for the two streams considered. The flow data refer to a volume of water passing through the channel over time (m^3/sec). For a longitudinal segment of the stream, the velocity of water flow (v, m/sec) was determined as the distance over time that a floating object took to cross 10 m (this was repeated three times, so the velocity considered is based on an average value). In addition, measurements of the width and depth of water were undertaken at three locations of the 10 m segment considered (the beginning, middle and end points of the segment); these parameters were calculated as an average and then used for determining the wet area (A, m^2) of the stream channel. Finally, the volumetric flow rate was calculated as the velocity multiplied by the wet area ($v \cdot A$, m^3/sec). Results showed a flow rate of 2400 l/min (0.04 m^3/sec) for the stream used in the audio-visual test, and 4800 l/min (0.08 m^3/sec) for the additional stream considered in this chapter.

It is worth noting that results of flow rates were obtained from measurements that are limited in terms of accuracy. It is also important to point out that the flow rates calculated for the streams might not be considered as comparable to the flows of the small to medium sized water features tested in the laboratory (flow rates ranging between 15 to 150 l/min) due to their high values (2400 and 4800 l/min). However, an explanation can be found considering that the calculated values of flow rates for the natural streams refer to a volumetric water flux passing through a channel, whilst the flow rate of the other water features consists of much smaller amounts of water coming out of a pump.

7.5.3 Discussion

Sound maps of individual water features showed that sound pressure levels at the receiver for an area of 20 m × 20 m around the structure vary in a range from 35 to 75 dBA for all the small to medium sized water features tested in the laboratory. It can also be observed that waterfalls are normally louder than fountains, jets and cascade, as previously pointed out by Galbrun and Ali (2013). Results in terms of sound maps vs. flow rates suggested that the effect of flow rate on predicting sound pressure levels in the far field is not really noticeable in the case of waterfalls whilst, for fountains, a larger range of variation in sound pressure levels was noticed when changing their flows. This was previously demonstrated by Galbrun and Ali (2013) who investigated the impact of design factors on acoustical and psychoacoustical parameters. Waterfalls have a small range of variation in L_{Aeq} and can easily produce higher sound pressure levels compared to fountains, jets and cascades, as they can use higher flow rates and larger amount of water which produce more bubbles (Galbrun & Ali, 2013). In the case of a natural stream, results showed that sound pressure levels can increase in a range of ~ +5 dBA by doubling its flow. It is worth noting that this result cannot be applied to all types of streams (the features tested in the field consist of 2-3 m wide streams with a shallow depth of water flowing (~ 0.10-0.15 m) over stones with a very low slope). However, it is possible that sounds from a stream producing higher sound pressure levels might be associated to sounds generated from water flowing from a series of steps and impacting over stones, and might then be easily confused with sounds from small waterfalls or cascades. For that reason, shallow flows of water over stones were included in this analysis as the only cases representative of a natural stream rather than streams generating higher impact sounds (e.g. impact of water flowing over stones or falling from steps or heights).

7.6 Sound maps for water features used over RTN

In this section, results in terms of sound maps for water features used over road traffic noise are presented. This part of the work aimed at identifying potential relaxation or pleasantness that can be achieved in areas around water features (waterfalls, fountains, cascades and streams) in the presence of road traffic noise. Different noise settings which are characterised by sound levels of road traffic noise ranging from 40 to 70 dB were considered. This was chosen in order to evaluate typical acoustic settings where water structures can be located (40 dB being quiet, 55 dB being not too quiet and not too noisy and 70 dB being noisy). According to field measurements carried out in previous studies, specific ranges of road traffic noise levels were identified for typical acoustic settings: 40-50 dB in suburban gardens (Watt et al., 2009); 60 to 70 dBA in an urban square close to a roadside (Nilsson et al. 2010); 60 to 65 dBA for a minor road, a major road and a freeway (De Coensel et al. 2011); 70 dBA as the median level (L_{50}) for a setting (on footpaths or in parks or building plazas) in proximity to roadways (Brown and Rutherford, 1994). In the work presented here, road traffic noise levels were assumed to be continuous (i.e., dense road traffic noise) with no noticeable presence of major intrusive peaks such as passing vehicles.

Three acoustic zones (‘water sounds dominant zone’, ‘optimum zone’ and ‘RTN dominant zone’) were defined for waterscapes located in different noise settings according to water sound levels comparable to RTN (see Table 7.3).This is illustrated in detail in section 7.3.

Additionally, results from sound maps were presented by taking into account the preferences obtained from the audio-visual tests (as shown in Chapter 4) in order to identify which types of water features are most effective for promoting relaxation as well as improving soundscape perception in the presence of road traffic noise. In this section, sound maps are shown for the four water structures rated as preferred in the audio-visual tests (ST, CA, FTW and SHW), with the exception of sound maps for water features used over RTN levels of 65 dBA and 70 dBA where NJT and PEW (least preferred in the tests) are also included because of the high sound pressure levels they can generate. It is also worth mentioning that although discussions on the results related to some of the water features which were negatively rated in the audio-visual tests are presented in this section, sound maps for all the types of water features can be found in Appendices G to M. These results consist of sound maps where water features are located in the middle of the edge of a 20 m × 20 m grid as shown in Figure 7.2. The different acoustic zones have been colour coded (dark colour: ’RTN dominant zone’, grey colour: ‘optimum zone’ and light grey colour: ‘water sound dominant zone’).

A summary of results is given upfront in Table 7.4, in order to help understanding all findings related to sound maps for water features used over RTN.

7.6.1 Sound maps for water features used over RTN of 40 dBA

Sound maps for water features used over a road traffic noise level of 40 dBA are presented in this section. Figure 7.10(a) shows sound maps for ST, CA, and FTW, but results for all the water features tested can be found in Appendix G. In the case of ST, the ‘optimum zone’ extends 8-15 m from the baseline of the natural stream, as shown in Figure 7.10(a). This means that the area where water sounds are dominant is restricted up to 7 m and road traffic noise becomes the principal sound at approximately 14 m from the stream. The ‘optimum zone’ for the cascade with four steps (CA) corresponds to an area of 14-17 m from the edge of the water feature, while this extends 18-23 m from the fountain with 37 upward jets (FTW). In the case of all waterfalls considered in this work (SHW, SEW and PEW) and the narrow jet (NJT), water sounds are dominant in all the grid of 20 m × 20 m around the water structures, whilst the ‘optimum zone’ extends 3-4 m from the edge of a large jet (LJT) (Appendix G).

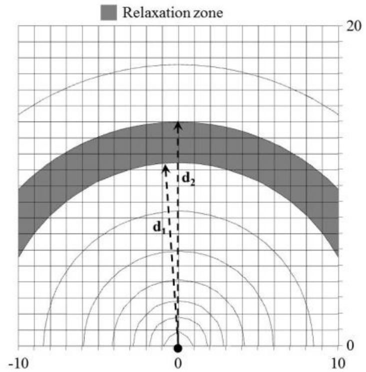
Furthermore, the ‘optimum zone’ extends 16-20 m from a dome fountain (DF), whilst this area is restricted to 12-14 m from a foam fountain (FF). These findings can also be found in Table 7.4.

7.6.2 Sound maps for water features used over RTN of 45 dBA

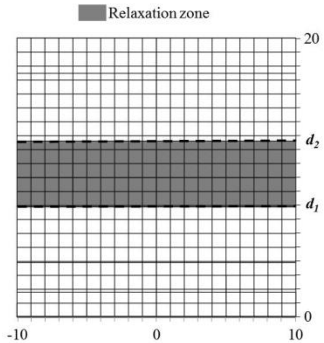
In the presence of a road traffic noise level of 45 dBA, the ‘optimum zone’ extends 2-5 m from a natural stream (ST), as shown in Figure 7.10(b). Relaxation can be promoted in an area corresponding to 9-12 m from the edge of a cascade (CA), while this extends 12-15 m from a fountain with multiple upward jets (FTW) (Figure 7.10(b)). In the case of SEW, PEW, SHW and NJT, these water features generate louder sound levels comparable to RTN of 45 dBA such that water sounds are dominant in all the grid of 20 m x 20 m considered (with the only exception of SHW, for which water sounds are dominant up to 15 m from the waterfall and the ‘optimum zone’ extends 16-21 m) (see Appendix H for details). Furthermore, the ‘optimum zone’ corresponds to an area of 11-14 m distance

Table 7.4 Extension of the 'optimum zone' for each water feature used over RTN levels ranging between 40 to 70 dBA. The extension is given in terms of optimal distances [d_1, d_2] from the base of the water structure (refer to Table 3.1. for acronyms and details of the water features tested).

Sound code	Impact material	Flow rate (l/min)	Height (m) &Width (m)	Audio-visual preference	'Optimum Zone' – Optimal distances from the water structure [d_1, d_2] (m)						
					RTN 40 dBA	RTN 45 dBA	RTN 50 dBA	RTN 55 dBA	RTN 60 dBA	RTN 65 dBA	RTN 70 dBA
ST	Stones and shallow water	2400	0.10-2.0	High	8-15	2-5	0-1	-	-	-	-
CA	Stones (pebbles)	15	-	High	14-18	9-12	5-7	3-4	1-2	0-0.7	-
FTW	Water	30	-	High	18-23	12-15	7-11	4-6	2-3	0-1	-
SHW	Water	30	0.5 - 1.0	High	25-33	16-21	11-15	7-9	4-5	2-3	0-1
DF	Water	40	-	Moderate	16-20	11-14	6-9	3-5	8-3	0-1	-
FF	Stones & boulders	30	-	Moderate	12-14	7-10	4-6	2-3	0-1	-	-
SEW	Water	30	0.5 - 1.0	Low	32-43	20-27	14-17	9-12	5-7	3-4	1-2
LJT	Water	15	-	Low	3-4	1-2	0-0.7	-	-	-	-
PEW	Water	120	1.0 - 1.0	Low	33-44	21-28	14-18	10-12	5-8	3-4	1-2
NJT	Water	15	-	Low	32-43	20-27	14-17	9-12	5-7	3-4	1-2



Point source – d_1 and d_2 (m) are the radiuses of the small and large circles respectively from the centre of the water structure



Line source – d_1 and d_2 (m) are the perpendicular distances from the base of the water structure.

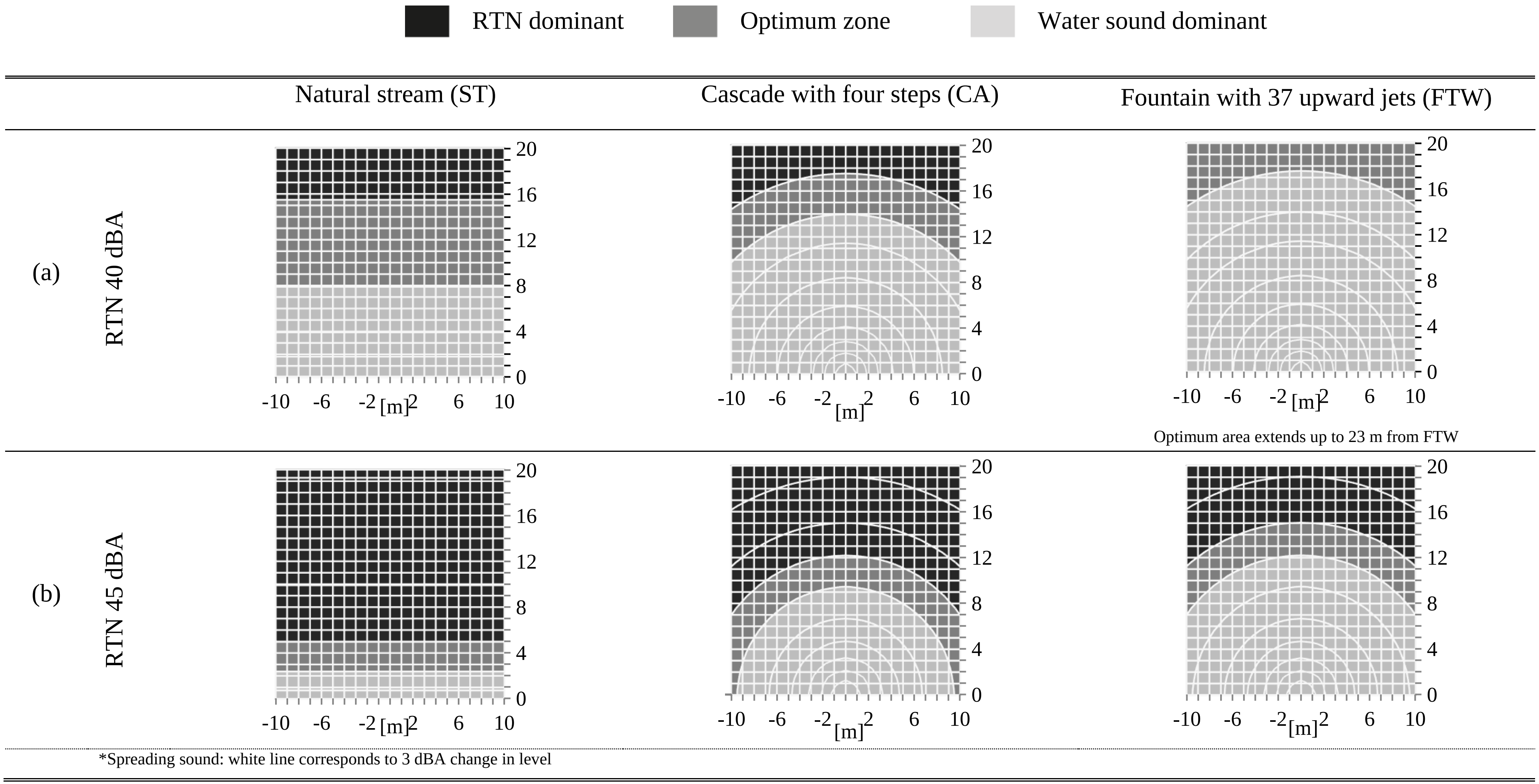


Figure 7.10 Sound maps for water features (ST, CA and FTW) used over RTN 40-45 dBA.

from the dome fountain (DF), whilst this zone extends 7-10 m from the foam fountain (FF). On the contrary, the large jet (LJT) is not able to produce sound levels comparable to a RTN of 45 dBA, meaning that the 'optimum zone' is restricted to 1-2 m from the fountain (Appendix H). A summary of these results is given in Table 7.4.

7.6.3 Sound maps for water features used over RTN of 50 dBA

Figure 7.11 shows sound maps for ST, CA and FTW used over RTN 50 dBA. It can be noted that the 'optimum zone' is restricted to 1 m from the natural stream (ST), whilst this extends 5-7 m from CA and 7-11 m from FTW. Relaxation can be promoted in an area from 11 m to 14 m from the small holes waterfall (SHW), and this is restricted to 4-6 m from the foam fountain (FF) and to 6-9 m from the dome fountain (DF) (Appendix I). Furthermore, water sounds are similar or not less than 3 dB below the RTN level of 50 dBA in a zone up to 13 m from SEW, PEW and NJT: the 'optimum zone' corresponds to an area between 14-18 m from SEW and NJT, whilst this extends

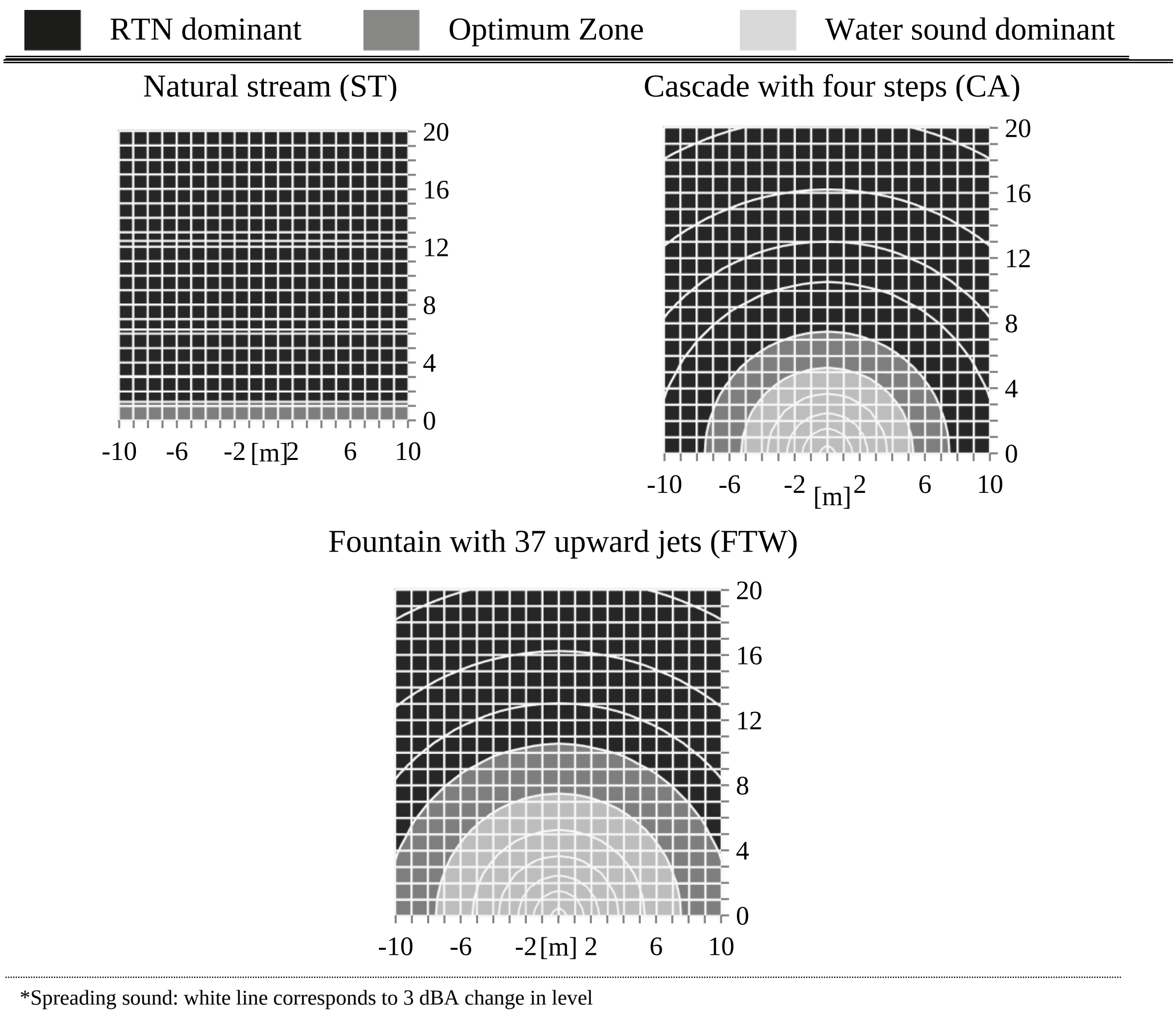


Figure 7.11 Sound maps for water features over RTN 50 dBA.

14-18 m from PEW (Appendix I). Finally, the optimum zone extends up to 0.7 m from the large jet (LJT) (Appendix I). These findings can also be found in Table 7.4.

7.6.4 Sound maps for water features used over RTN of 55 dBA

In an acoustic setting with a RTN level of 55 dBA, results showed that the natural stream (ST) and the large jet (LJT) cannot be used for generating sound levels comparable to RTN, meaning that no 'optimum zone' around these water features can be found (Appendix J). For the cascade with four steps (CA), a 'optimum zone' corresponds to an area 3-4 m from the edge of the structure, whilst it extends 4-6 m from the fountain with multiple upward jets (FTW) (Figure 7.12(a)). In the case of a small holes waterfall (SHW), relaxation can be improved at 5-7 m from the feature (Figure 7.12(a)). Additionally, the 'optimum zone' is limited to 3-5 m from the dome fountain (DF), and to 2-3 m from the foam fountain (FF) (Appendix J). Finally, results showed that the 'optimum zone' extends 10-12 m from PEW (plain edge waterfall), whilst this is restricted to 9-12 m from SEW (sawtooth edge waterfall) and NJT (narrow jet) (Appendix J). These results are summarised in Table 7.4.

7.6.5 Sound maps for water features used over RTN of 60 dBA

In the case of RTN levels of 60 dBA, results showed that road traffic noise is the only dominant sound in a grid of 20 m × 20 m for the natural stream (ST) and the large jet (LJT) (Appendix K). Figure 7.12(b) shows sound maps for CA, FTW and SHW over RTN 60 dBA. A restricted area around these water features was identified as the 'optimum zone' (up to 2 m from CA, 3 m from FTW and 4 m from SHW). Results also showed that the 'optimum zone' is restricted to 2-3 m from the dome fountain (DF), and this is limited to 1 m from the foam fountain (FF) (Appendix K). However, waterfalls (SEW, PEW) as well as the narrow jet (NJT) are able to generate sound pressure levels similar to RTN 60 dBA and the 'optimum zone' is extending to an area between 5 m to 7-8 m around the water features (Appendix K). A summary of these findings is given in Table 7.4.

7.6.6 Sound maps for water features used over RTN of 65 dBA

Results showed that the natural stream (ST), foam fountain (FF) and large jet (LJT) are not effective to generate sound pressure levels similar to RTN levels of 65 dBA, meaning that 'optimum zones' cannot be found for these water features (Appendix L). Furthermore, the 'optimum zone' is restricted to a small area close to most of the water features tested (up to 1.5 m from FTW and up to 3 m from SHW (Figure 7.13(a)), up to

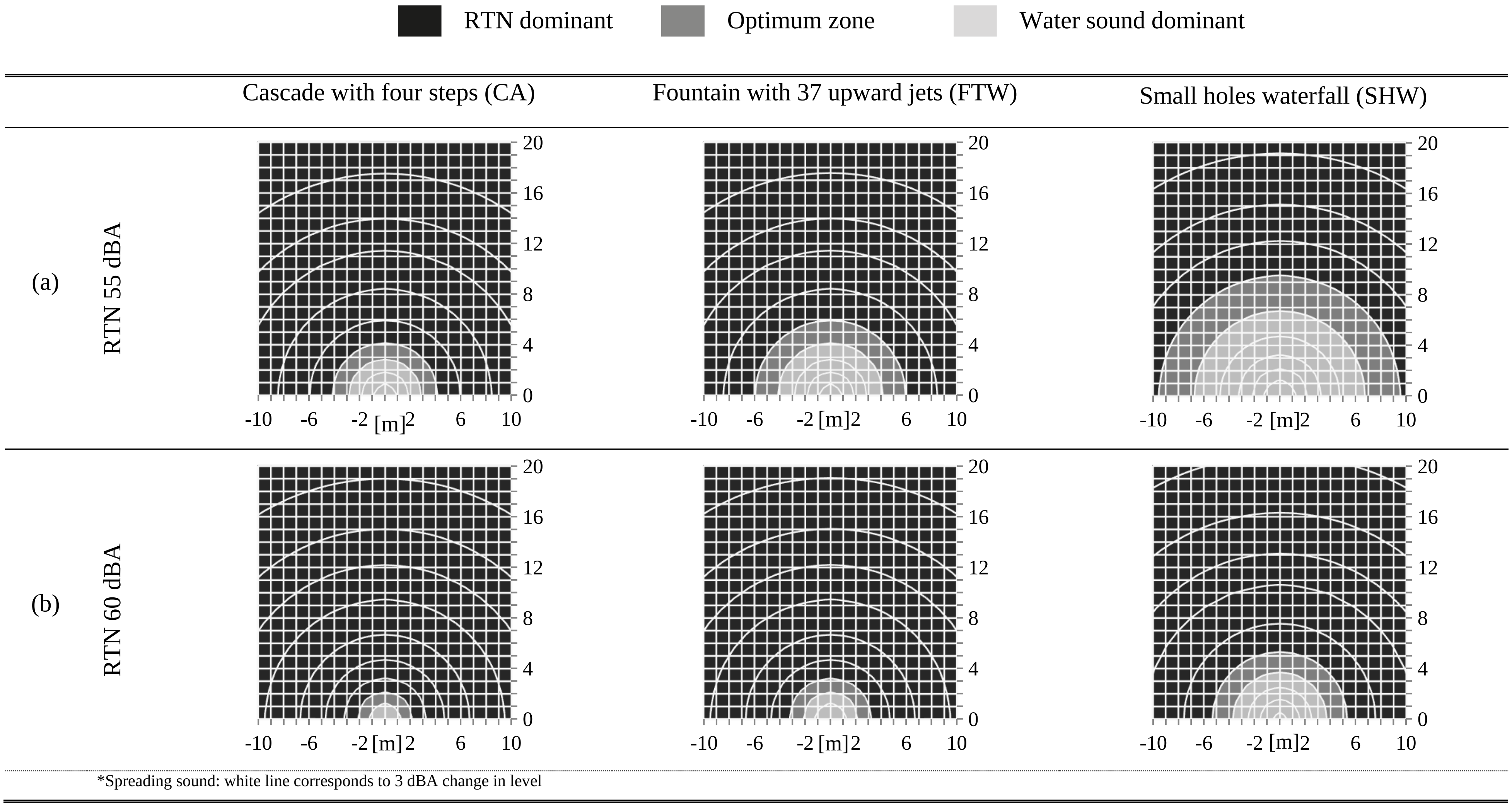


Figure 7.12 Sound maps for water features (CA, FTW and SHW) used over RTN 55-60 dBA.

0.7 m from CA and up to 1 m from DF (Appendix L). Results also showed that the sawtooth and plain edge waterfalls (SEW and PEW) and the narrow jet (NJT) are the most effective features to be used over RTN 65 dBA, generating water sound levels comparable to RTN in an area between 3-4 m from the edge of the water structure (sound maps for SEW and NJT are given in Appendix L, while sound map for PEW is shown in Figure 7.13(a)). However, the 'optimum zone' is restricted to a short distance of 2-3 m from the small holes waterfall (SHW) (Figure 7.13(a)). A summary of findings can also be found in Table 7.4.

7.6.7 Sound maps for water features used over RTN of 70 dBA

Results suggested that most of the water structures tested are not able to generate sound levels comparable to RTN levels of 70 dBA. In fact, road traffic noise was found to be dominant in the entire grid of 20 m × 20 m in the case of ST, CA, FTW, DF, FF and LJT (Appendix M). The only exceptions are represented by the small holes and plain edge waterfalls (SHW and PEW) for which the 'optimum zone' extends up to 1 m and 2 m respectively from the edge of the structures (Figure 7.13(b)). Furthermore, similar trend was observed for the sawtooth edge waterfall (SEW) and the narrow jet (NJT): the 'optimum zone' extends up to 2 m from the features (meaning that there is no area where water sounds are dominant) (Appendix M). A summary of these results can also be found in Table 7.4.

7.6.8 Discussion

In order to identify the effectiveness of small to medium sized water features (waterfalls, cascades, fountains and streams) for promoting relaxation in the presence of road traffic noise, results of sound maps showed three acoustic zones ('RTN dominant zone', 'optimum zone' and 'water sound dominant zone') where potential relaxation or pleasantness can be achieved depending on the sound pressure levels of each type of water structure used in a specific noise setting. It is implied that relaxation can also be promoted outside the boundaries of the 'optimum zone', as tranquillity can still be achieved for low levels of masking, as demonstrated by Watts et al. (2009).

Results showed that waterfalls and narrow jets can generate sound levels comparable to RTN levels ranging from 40 to 70 dBA. Fountains with multiple upward jets and cascades promote relaxation in the presence of RTN levels ranging between 40 to 60 dBA, whilst dome and foam fountains might be used over RTN levels from 40 to 55

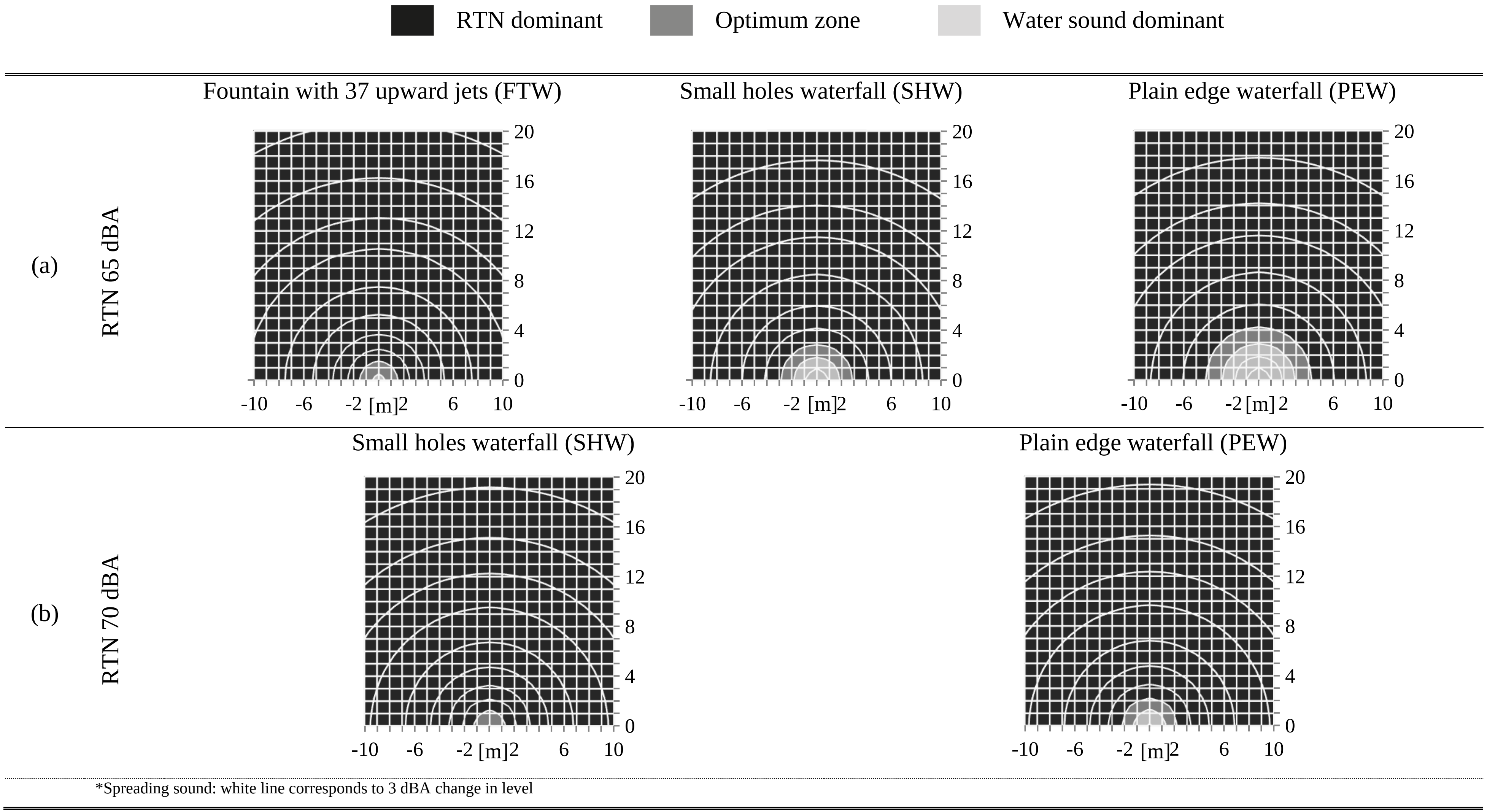


Figure 7.13 Sound maps for water features (FTW, SHW and PEW) used over RTN 65-70 dBA.

dBA. In addition, a natural stream and a large jet can produce sound levels comparable to a range of RTN levels from 40 to 50 dBA.

The analysis of the acoustic zones around a natural stream showed that the optimum zone extends up to 15 m and 5 m from the water structure in the presence of RTN levels of 40 and 45 dBA respectively (very small 'optimum area' was found for a stream used over RTN 50 dB, up to 1 m from the feature). This suggests that a natural stream is mostly effective for promoting relaxation in quiet environments such as suburban areas (40-45 dBA) distant from main traffic routes, and tends to improve the soundscape perception, being the preferred feature in the audio-visual tests (Chapter 4). Furthermore, cascades and fountains with multiple upward jets can produce sound pressure levels comparable to road traffic noise levels ranging between 40 to 60 dBA. Relaxation could be achieved in an area up to 17 m (RTN 40 dBA), 12 m (RTN 45 dBA), 7 m (RTN 50 dBA), 4 m (RTN 55 dBA), 2 m (RTN 60 dBA) and just 0.7 m (RTN 65 dBA) from the edge of the cascade with four steps (CA). In the case of the fountain with multiple upward jets (FTW), the 'optimum zone' extended up to 23 m from the water feature in the presence of RTN 40 dBA, 15 m for RTN 45 dBA, 11 m for RTN 50 dBA, 6 m for RTN 55 dBA, 3 m for RTN 60 dBA and 1.5 m for RTN 65 dBA. Results suggest that cascades and fountains with multiple upward jets might be used in acoustic environments characterised by quiet as well as noisy levels (e.g. suburban areas as well as urban areas such as parks or squares) of road traffic noise in order to improve relaxation and peacefulness. However, the 'optimum zone' consists of a very small area around these water features when used over RTN levels of 60-65 dBA.

In the case of the small holes waterfall (SHW), results suggest that it might also be used to promote relaxation, having been positively rated in the audio-visual tests (4th ranking position out of 10 features). Furthermore, this waterfall can generate sound pressure levels comparable to RTN levels of 40 to 65 dBA. This means that relaxation can be improved in different areas around this waterfall based on the roadside setting (area up to 33 m for RTN 40 dBA, 21 m for RTN 45dBA, 14 m for RTN 50 dBA, 7 m for RTN 55 dBA, 4 m for RTN 60 dBA, 3 m for RTN 65 dBA and a very small area of up to 1 m for RTN 70 dBA).

Results showed that the sawtooth (SEW) or plain edge waterfall as well as the narrow jet (NJT) can produce sound pressure levels comparable to RTN levels of 40 to 70 dBA. Although it is possible to identify potential 'optimum zones' for various acoustic settings (environments characterised by quiet or noisy noise levels), results suggested that these water features tend not to be preferred for improving the soundscape perception in the context of relaxation (these features were negatively rated in the audio-visual tests). In addition, a similar trend was found for the dome (DF) and foam (FF) fountains (rated respectively 5th and 6th out of 10 features). These water features might be used in acoustic environments affected by RTN levels ranging between 40 to 60 dBA, but their impact on soundscape perception might not be as positive as the impact of the preferred water features.

7.7 Sound maps for water features with different flow rates and RTN levels

In this section, sound maps are presented for the preferred water features (ST, CA, FTW and SHW) operating under different flow rates and used over RTN levels ranging between 40 to 65 dBA. This analysis aimed at evaluating how the 'optimum zone' extends by varying the flow rate of the water features tested. Although water features with different flow rates were not tested in terms of audio-visual preferences, results are shown in terms of optimal distances from the water features for the 'optimum zone'. However, further research would be needed in order to investigate the perceptual assessment of water features with different flow rates used over road traffic noise in the context of relaxation. Results can be found in Appendix N, and a summary of results is also given in Table 7.5.

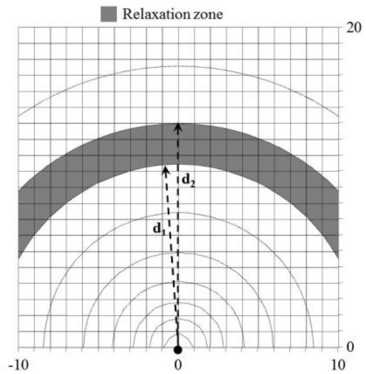
7.7.1 Results

In the case of the natural stream, ST (shallow depth of water flowing over stones), results showed that the area covered by the 'optimum zone' can increase when the water flow rate is doubled (from 2400 to 4800 l/min) (Figure 7.14). A large increase can be observed for streams used over RTN levels of 40-45 dBA (~ +17 m for RTN 40 dBA; and ~ +15 m for RTN 45 dBA, as the flow is doubled). Furthermore, the 'optimum zone' extends up to 1 m and 8 m for the stream with a flow rate of 2400 l/min and 4800 l/min respectively, when used over RTN levels of 50 dBA. Finally, the stream with a flow rate of 2400 l/min is not able to generate sound pressure levels comparable to RTN levels of 55 dBA, but the 'optimum zone' extends up to 2 m from the stream with a higher flow rate (4800 l/min).

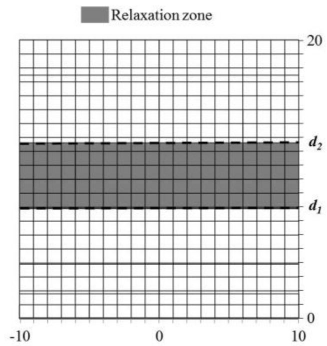
In the case of the cascade with four steps (CA) used over RTN 40 dBA, results showed that the 'optimum zone' extends up to 13 m, 17 m, 20 m and 24 m considering a flow rate of 5, 15, 30 and 60 l/min respectively, as shown in Table 7.5 (Appendix N).

Table 7.5 Extension of the ‘optimum zone’ for the preferred water features (ST, CA, FTW and SHW) operating under different flow rates and used over RTN levels ranging between 40 to 65 dBA. The extension is given in terms of optimal distance [d_1, d_2] from the base of the water structure.

		‘Optimum Zone’ – Optimal distances from the water structure [d_1, d_2] (m)					
Sound code	Flow rate (l/min)	RTN 40 dBA	RTN 45 dBA	RTN 50 dBA	RTN 55 dBA	RTN 60 dBA	RTN 65 dBA
		(m)	(m)	(m)	(m)	(m)	(m)
ST	2400	8-15	3-5	0-1	-	-	-
	4800	22-32	13-20	4-8	0-2	-	-
CA	5	10-13	5-8	3-4	1-2	-	-
	15	14-17	9-12	5-7	3-4	1-2	-
	30	16-20	11-14	7-9	4-5	2-3	-
	60	18-24	13-16	8-11	4-6	2-3	-
FTW	10	8-11	4-6	2-3	0-2	-	-
	20	14-17	9-12	5-7	3-4	1-2	-
	30	18-23	12-15	7-11	4-6	2-3	-
	40	23-31	15-19	11-13	6-9	3-5	-
SHW	15	20-27	14-17	9-12	5-7	3-4	1-2
	30	25-33	16-21	11-14	7-9	4-5	2-3



Point source – d_1 and d_2 (m) are the radiuses of the small and large circles respectively from the centre of the water structure



Line source – d_1 and d_2 (m) are the perpendicular distances from the base of the water structure.

Additionally, the size of the ‘optimum zone’ increased in a range of ~ +7 m / +8 m on average for a cascade with a flow rate varying from 5 to 60 l/min in the presence of RTN levels of 45 and 50 dBA respectively, while small variations in size were observed when used over RTN levels of 55 and 60 dBA (~ +4 m / +1 m respectively) (Table 7.5) (Appendix N).

Results related to the fountain with multiple upward jets (FTW) used over RTN levels of 40 and 45 dBA showed that the ‘optimum zone’ increases in size of ~ +20 m and + 13 m respectively when operating under flows ranging between 10 to 40 l/min (Table 7.5) (Appendix N). Furthermore, an increase of ~ +10 m and +6 m was found for the fountain when used over RTN levels of 50 and 55 dBA, while a small variation was observed in the presence of RTN levels of 60 dBA (Appendix N).

A similar trend was found for the small holes waterfall (SHW) operating under flow rates ranging between 15 to 30 l/min (Table 7.5) (Appendix N). Results showed a large increase of the ‘optimum zone’ (~ +6 m / +4 m) for this waterfall used over low RTN levels (40-45 dBA), whilst the ‘optimum zone’ expands in a range of + 2 m in the presence of RTN levels of 50 and 55 dBA (Appendix N). Additionally, an increase of the ‘optimum zone’ of + 1 m was observed for SHW used over RTN levels of 60 and 65 dBA by varying its flow rate (Table 7.5).

7.7.2 Discussion

In order to understand the effect of flow rate on the extension of the ‘optimum zone’, sound maps of the preferred water features used over RTN were developed by considering the features operating under different flow rates. Results showed a large increase in size of the ‘optimum area’ for ST, CA, FTW and SHW used over low levels of RTN ranging from 40 to 50 dBA (e.g. + 20 m for FTW used over RTN 40 dB by varying its flow from 30 to 40 l/min). However, in the presence of RTN levels of 55 dBA, a moderate increase in size (~ +4 m /+6 m) of the ‘optimum zone’ was observed for CA and FTW, while only a small increase was noted for ST and SHW. Additionally, a small variation in size of the ‘optimum zone’ was found for all water features used over RTN levels of 60 dBA, with the exception of the two natural streams which are not able to generate sound levels comparable to 60 dBA.

Furthermore, this analysis allowed evaluating the effect of flow rates on the extension of the ‘optimum zone’ in the case of water features used over RTN levels for which they

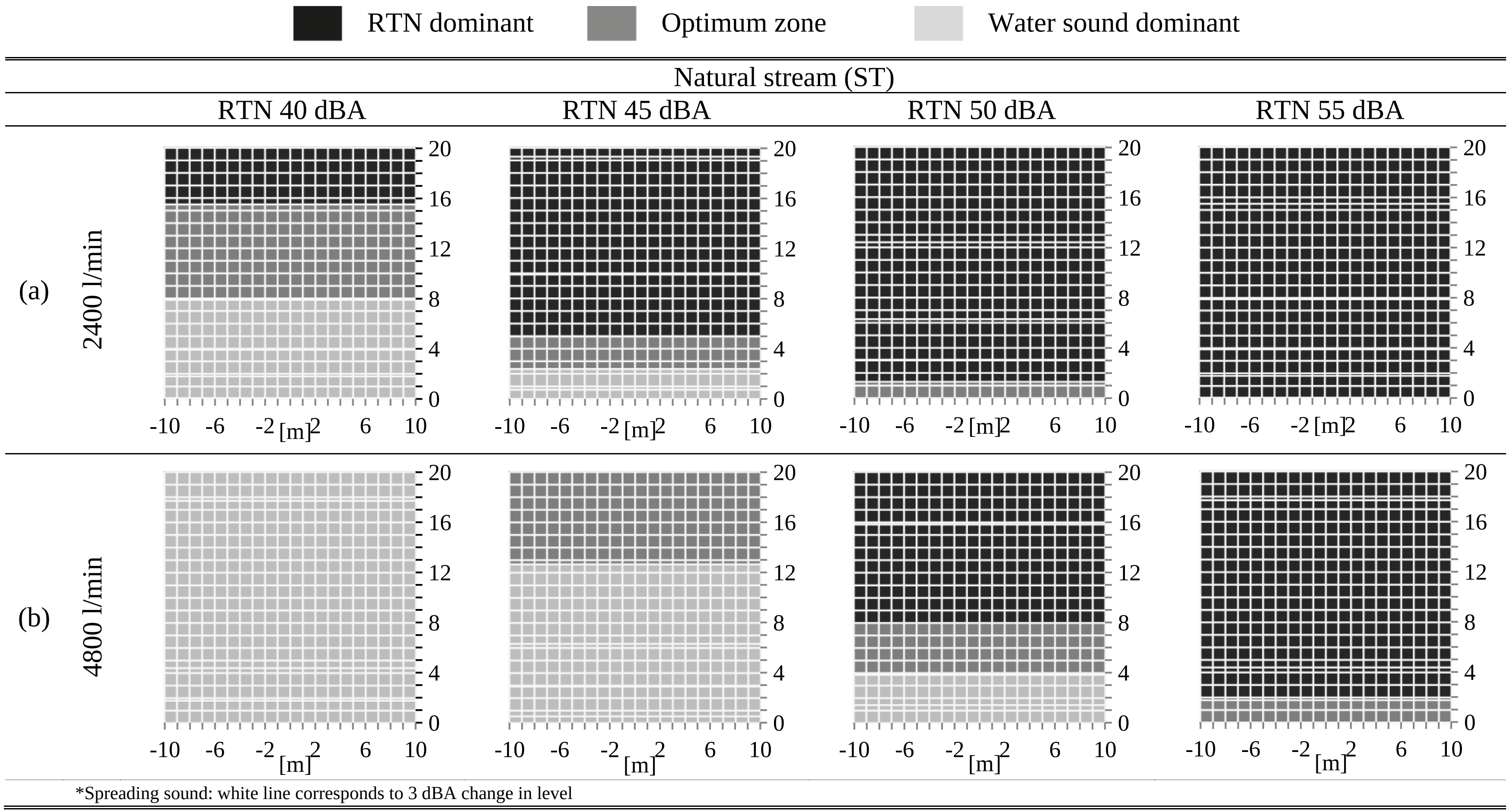


Figure 7.14 Sound maps for the natural stream (ST) with different flow rates and used over RTN levels ranging between 40 to 55 dBA.

are not able to produce high levels of relaxation (e.g. the natural stream used over 50-55 dBA). As observed from previous findings (refer to section 7.6), the ‘optimum zone’ is restricted to a very small area or completely absent for the natural stream (ST, 2400 l/min) used over RTN levels of 50-55 dBA. However, results from this analysis showed that the size of the ‘optimum zone’ can increase (~ +7 m / +2 m respectively) when the water flow doubles (shallow streams with flow rates ranging between 2400 to 4800 l/min). For the cascade with four steps (CA, 30 l/min) and the fountain with multiple upward jets (FTW, 30 l/min), the ‘optimum zone’ consists of a very small area in the presence of RTN levels of 60-65 dBA (see section 7.6). By increasing the flow rates, it is possible to expand the ‘optimum zone’ for these water features used over RTN 60 dBA (an increase of ~ +2 m for FTW operating under a flow increased to 40 l/min, as well as for the cascade with a flow rate increased from 30 to 60 l/min), whilst this area is still absent in the presence of RTN 65 dBA.

Although the size of potential ‘optimum zones’ can be increased considering water features operating under higher flow rates, further research would be needed in order to investigate the effect of flow rates on the perception of these water features, when used over RTN in the context of relaxation.

7.8 Sound maps for multiple water features used over RTN

Additional analysis was made for water features used over road traffic noise considering different positions of the structures in a grid of 20 m × 20 m, as shown in Figure 7.16. This allowed identifying how the extension of the ‘optimum zone’ can vary by having more than one water feature at different positions in the grid considered. This is particularly relevant for RTN levels for which the water features tested are not able to produce high levels of relaxation (e.g. sounds from the natural stream (ST, 2400 l/min) over RTN 50 dBA).

7.8.1 Results

Figure 7.16 shows sound maps for the natural stream (ST, 2400 l/min) over RTN 50 dBA where three (d), four (e) and five (f) water structures are located in a grid of 20 m × 20 m (as shown in Figure 7.15). Results showed that the ‘optimum zone’ is expanding to all the area of study when five features are located at the edges and the middle of the grid in the presence of RTN levels of 50 dBA (Figure 7.16(f)). However, road traffic noise levels of 50 dBA are still dominant in some areas of the grid when three/four

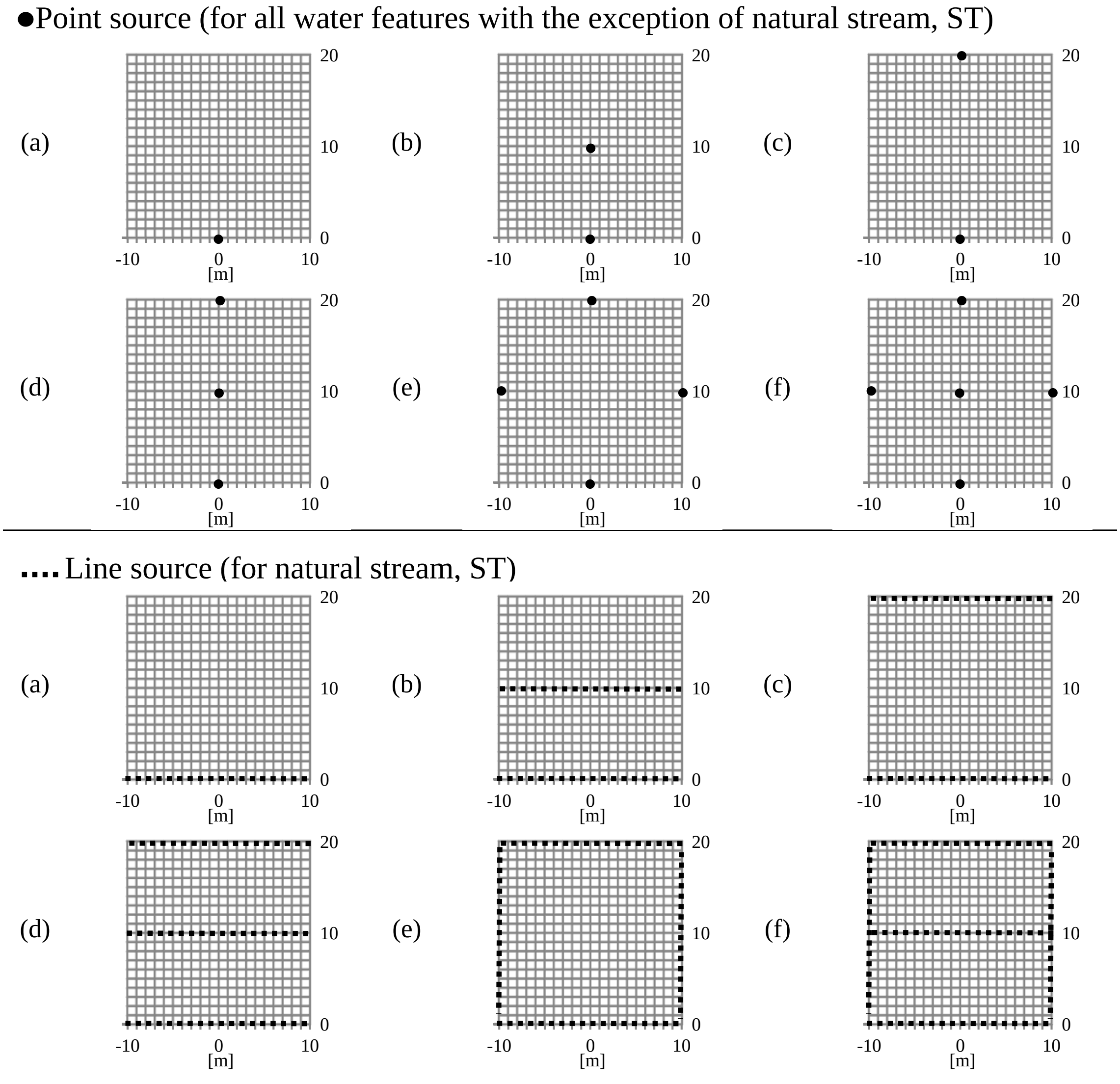


Figure 7.15 Different positions of water sound sources (point and line) in a grid of 20 m × 20 m.

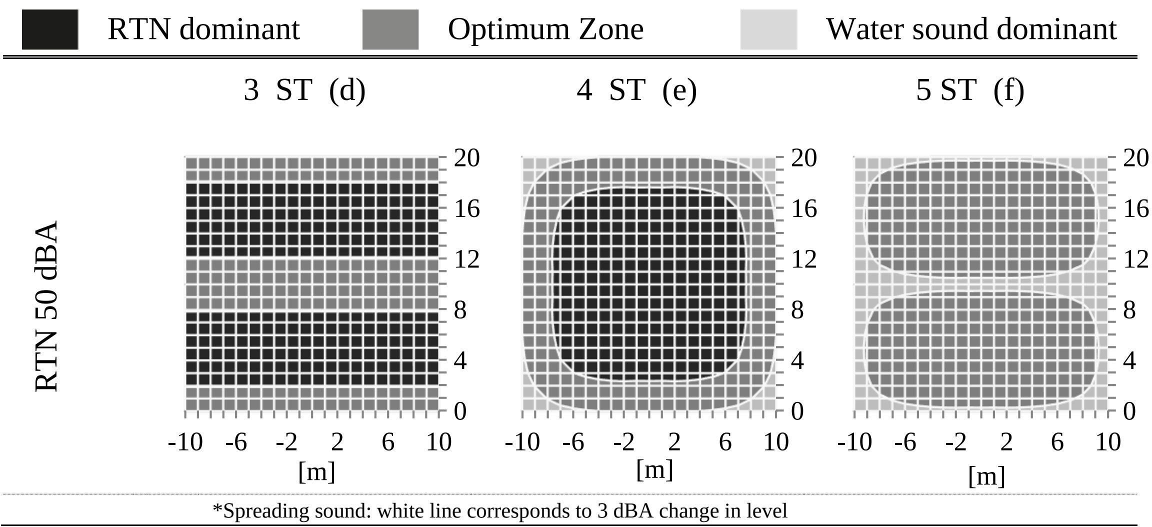


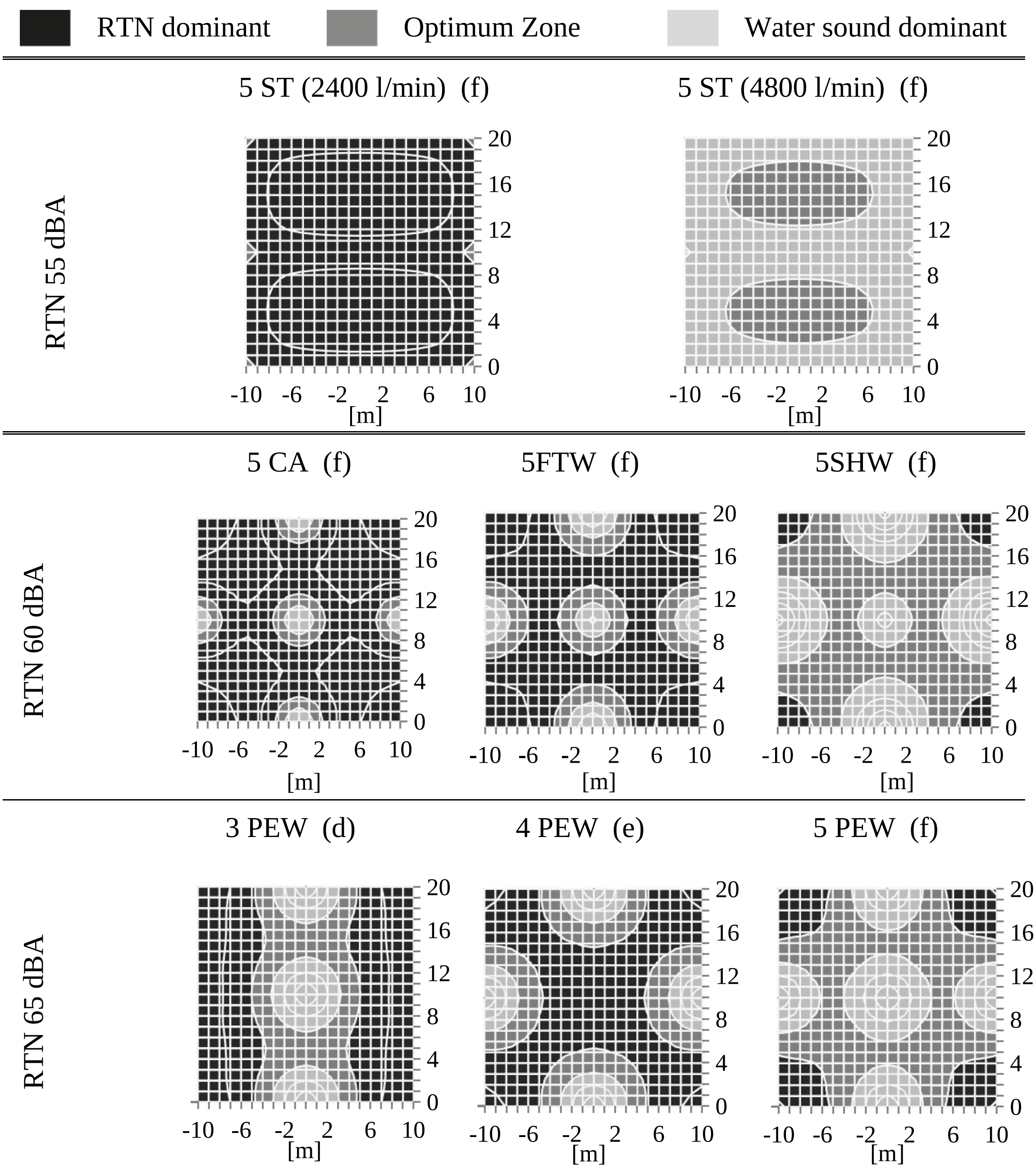
Figure 7.16 Sound maps for multiple natural streams used over RTN 50 dBA at different positions ((d)-(f)) in a grid of 20 m × 20 m.

natural streams are used (Figure 7.16(d-e)). Furthermore, results for the natural stream used over RTN levels ranging between 55-70 dBA showed that this type of water feature is not able to generate similar sound pressure levels, as no optimum zones can be identified even when more than one stream is installed in the grid considered (Appendices S to V). Finally, additional analysis pointed out that multiple natural streams operating under a higher flow rate can be used over RTN levels of 55 dBA: the 'optimum zone' is expanding almost the entire grid of 20 m × 20 m when three/four/five streams operating under a flow of 4800 l/min are used (Figure 7.17).
A similar trend was found for sound maps with multiple cascades (CA) and fountains with upward jets (FTW). The 'optimum zone' is still limited to a very small area around the structures (Figure 7.17) or completely absent when several of these water features were used over RTN levels ranging between 60 to 70 dBA. In the case of the small holes waterfall (SHW), results showed that five features are not able to produce sound levels comparable to RTN levels of 65-70 dBA and increase the size of the 'optimum zone' around the waterfalls in a grid of 20 m × 20 m. However, four/five small holes waterfalls are able to promote a 'optimum zone' extending almost the entire grid considered in the presence of RTN levels of 60 dBA (Figure 7.17).

Although the plain edge waterfall was rated as least preferred in the audio-visual tests, the combination of several of these waterfalls is able to generate sound pressure levels comparable to noisy levels of road traffic noise (RTN 65-70 dBA) in a grid of 20 m × 20 m, as shown in Figure 7.17. For that reason, this water feature (PEW) was included in this analysis (Appendices O and P).

7.8.2 Discussion

The use of multiple water features does not always expand the optimum zone in the presence of a specific RTN setting. This means that the 'optimum zone' is restricted to a very small area around the water features or completely absent even when more than one structure is installed in a grid of 20 m × 20 m. Among the preferred water features of the audio-visual tests, this occurs for multiple natural streams used over RTN levels ranging between 55 to 70 dBA, cascades and fountains with multiple upward jets in the presence of RTN levels from 60 to 70 dBA, and small holes waterfalls over RTN levels of 65-70 dBA. These confirm results illustrated in section 7.5 according to which small to medium sized water features might not be really effective in improving relaxation in acoustic settings where levels of road traffic noise are equal to or higher than 60 dB,



*Spreading sound: white line corresponds to 3 dBA change in level.

Figure 7.17 Sound maps for multiple ST(operating under different flow rates) used over RTN 55 dBA; multiple CA, FTW and SHW used over RTN 60 dBA and multiple PEW used over RTN 65 dBA at different positions in a grid of 20 m × 20 m.

even if they have been rated as preferred for enhancing the soundscape perception. This excludes waterfalls and single jets which are more effective in generating sound levels comparable to high RTN levels, but are least preferred for improving relaxation.

However, results showed that multiple cascades and fountains with multiple upward jets (5 CA and 4 FTW) might be used at different positions in the grid of study in order to increase the extension of the optimum zone in the presence of a RTN level of 55 dBA. A similar trend was found for multiple small holes waterfalls used at different positions over a RTN level of 60 dBA.

Additionally, results illustrated that the ‘optimum zone extends through the entire grid of 20 m × 20 m when five natural streams are used over a RTN level of 50 dBA. However, this does not represent a functional design solution, suggesting that natural streams with a flow rate under 2400 l/min might not be used for improving relaxation in the presence of RTN levels higher than 50 dBA. Moreover, additional analysis showed that multiple streams operating under higher flows (4800 l/min) are effective in improving relation in the presence of RTN levels of 55 dBA. Although, the stream with a low flow rate was the only feature included in the audio-visual preferences tests, the two features could be considered perceptually similar, as these produce waters sound showing analogous characteristics.

7.9 Sound maps for combinations of different water features used over RTN

In this section, sound maps for combinations of different water features used over road traffic noise are given. This analysis was made to understand the extension of the three acoustic zones when two types of water features are used in combination in the presence of road traffic noise. Sound maps were developed for water features (with the exception of the stream) which are not able to produce sound levels comparable to RTN levels ranging between 55 to 70 dBA, but are preferred in view of improving relaxation. The natural stream represents the only feature which was not included in this analysis, as previous results showed that multiple streams are not able to generate sound levels

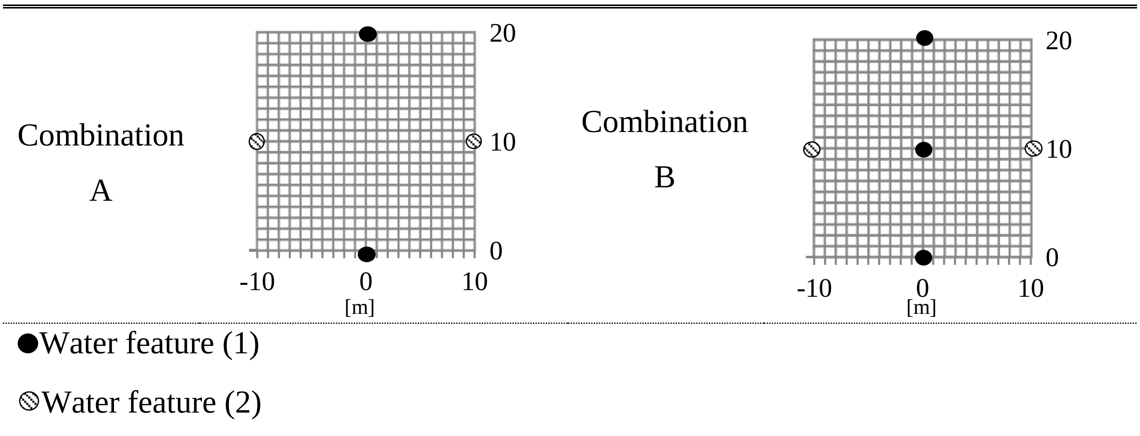


Figure 7.18 Different positions for two types of water features (point sources) in a grid of 20 m × 20 m.

comparable to RTN levels higher than 55 dBA (refer to section 7.8). Two types (water feature (1) and water features (2)) were considered at different positions (combinations A and B) in a grid of 20 m × 20 m, as shown in Figure 7.18. Results for different combinations of CA, FTW, SHW and PEW for RTN levels of 55-70 dBA can be found in Appendices Q to T.

7.9.1 Results

Figure 7.19(a) shows sound maps where two types of water features are combined together at different positions (combination A, four structures of two different types as shown in Figure 7.18) in a grid of 20 m × 20 m (e.g. CA + FTW, CA + SHW and FTW + SHW) in the presence of a RTN level of 55 dBA. Results suggest that combinations between cascades (CA), fountains with multiple upward jets (FTW) and small holes waterfalls (SHW) can generate a 'optimum zone' extending almost the entire grid considered when they are used over RTN levels of 55 dBA. On the contrary, road traffic noise is largely dominant when combinations of cascades and fountains with multiple upward jets are used in the presence of RTN 60 dBA (Appendix P). However, the 'optimum zone' consists of a larger area when small holes waterfalls are combined with fountains with multiple upward jets over RTN 60 dBA (Figure 7.19(b)). In the case of settings with RTN levels ranging between 65 to 70 dBA, combinations of FTW, CA and SHW are not able to generate sound levels comparable to RTN, meaning that no 'optimum zone' can be found (Appendices S and T). However, results for combinations of plain edge (PEW) and small holes (SHW) waterfalls show a 'optimum zone' expanding to a large area in the presence of RTN 65 dBA (Figure 7.19(c)).

7.9.2 Discussion

Among the preferred water features, cascades and fountains with multiple upward jets might be used together or in combination with small holes waterfalls in order to promote relaxation in an extended area affected by a RTN level of 55 dBA. However, combinations of cascades and fountains with multiple upward jets (but no small holes waterfalls) are not effective to promote a 'optimum zone' in the presence of RTN levels ranging between 60 to 70 dBA. Nevertheless, relaxation can be achieved by combining small holes waterfall with fountains with multiple upward jets in the presence of a RTN level of 60 dBA.

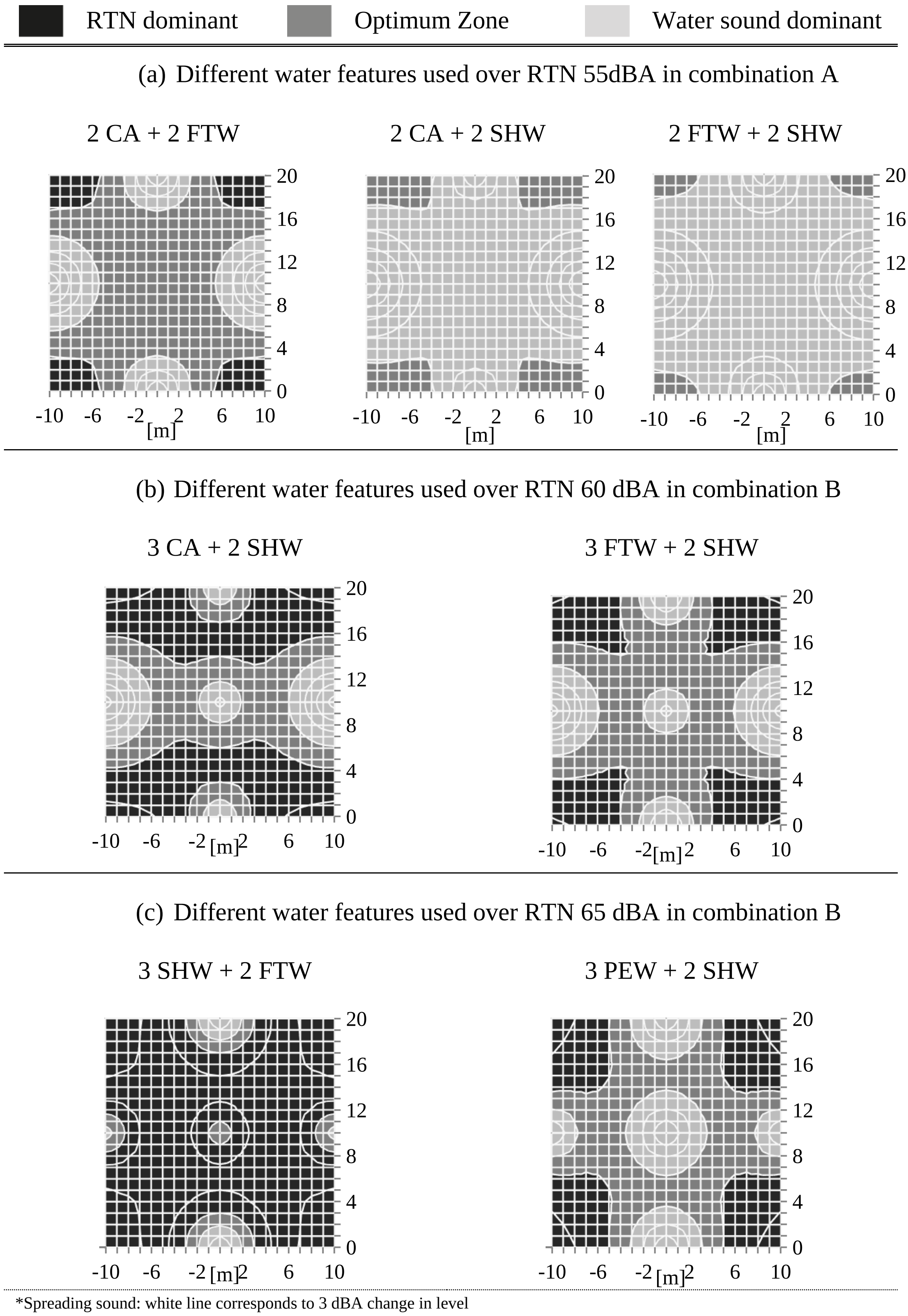


Figure 7.19 (a)-(c) Sound maps for combinations (A or B) of various water features over RTN levels of 55-60-65 dBA in a grid of 20 m × 20 m.

For settings with RTN levels ranging from 65 to 70 dBA, combinations of preferred water features (CA, FTW and SHW) do not provide an effective design solution in view of improving relaxation. Although plain edge waterfalls tend not to be preferred, combinations of these features with small holes waterfalls represent an effective solution in increasing the size of the ‘optimum zone’ when they are used over high levels of road traffic noise. For that reason, further research would be needed to evaluate their effectiveness in promoting relaxation in noisy settings.

7.10 Conclusions

This chapter illustrated results of sound maps for a wide range of small to medium sized water features (waterfalls, cascades, fountains tested in the laboratory and a natural stream, the only feature tested in the field) which can be used over road traffic noise in view of improving soundscape perception and promoting relaxation. Predictions of sound pressure levels at different receiver positions were made by using sound propagation models based on the type of the source considered (point or line) and assuming a water feature located in the middle of an edge in a grid 20 m × 20 m. These results were then presented in terms of sound maps where intervals of sound pressure levels (5 dBA) were assigned to different greyscale colours/patterns.

Results of sound maps for individual water features showed that waterfalls tend to produce louder sound levels than fountains, jets and cascade, as already highlighted by Galbrun and Ali (2013). In addition, results of sound maps for water features tested in the laboratory with different flow rates’ conditions showed that the effect of flow rate is less noticeable for waterfalls, whilst larger variations in sound pressure levels were found for fountains. This was also previously pointed out by Galbrun and Ali (2013), as identical water features were used in that work. In the case of the features tested in the field (natural streams with a shallow depth of water flowing over stones), results showed that an increase of sound pressure levels (~ +5 dBA) can be generated by doubling the flow rate. However this finding cannot be applied to all types of streams, as sounds from a stream producing higher sound pressure levels could be easily confused with sounds from small waterfalls or cascades, due to impact sounds such as water flowing over stones and falling from steps or heights. For that reason, only shallow streams were included in this analysis rather than streams with higher impact sounds.

The predicted values of sound pressure levels were then used to investigate the effectiveness of each type of water feature tested for promoting relaxation/pleasantness in various acoustic settings characterised by different road traffic noise levels. Three acoustic zones (‘RTN dominant zone’, ‘optimum zone’ and ‘water sound dominant zone’) were defined by making assumptions taking into account findings of previous research (Brown and Rutherford, 1994) (Nilsson *et al.*, 2010) (You *et al.*, 2010) (Jeon *et al.,* 2012) (Galbrun and Ali, 2013) (Axelsson *et al.*, 2014). The ‘water sound dominant zone’ was defined here as the area close to the water structure where road traffic noise might be still audible but water sound is the dominant sound (water sounds levels are higher than RTN levels). The ‘optimum zone’ was defined as the area where water sound levels are similar or not less than 3 dB below RTN, corresponding to the levels which were found to be preferred for relaxation by previous research (You *et al.*, 2010) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013). In this zone, soundscape perception can be improved and relaxation can be achieved. The ‘RTN dominant zone’ was defined as the area where people might still detect water sounds but road traffic noise is dominant because water sounds levels are lower than RTN levels minus 3 dB. Finally, the definition of the three acoustic zones assumes that relaxation can be also achieved outside the ‘optimum zone’, as tranquillity can still be improved for low levels of masking (Watts *et al.*, 2009).

The analysis of different acoustic zones around water features used over RTN (ranging from 40 to 70 dBA) showed that a natural stream tends to be most effective for promoting relaxation in quiet environments such as suburban areas (40-45 dB) distant from main traffic routes, and tends to improve the soundscape perception, being the preferred feature in the audio-visual tests. In the case of the cascade with four steps, results suggest that this might be used to promote relaxation in the presence of RTN levels of 40 to 60 dBA, having also been positively rated in the audio-visual tests (2nd ranking position out of 10 features). Furthermore, fountains with multiple upward jets and waterfalls made with small holes’ edges might be used in acoustic environments characterised by quiet as well as noisy levels (e.g. suburban areas as well as urban areas such as parks or squares) of road traffic noise (RTN levels ranging from 40 to 65 dBA). Additionally, these water features can have a positive impact on subjective perception according to results obtained in terms of audio-visual preferences, the fountain was ranked 3rd out of 10 features, whilst the small holes waterfall was ranked 4th. However, the optimum zone in the presence of RTN levels of 60-65 dBA consists of a very small area around the fountain with multiple upward jets.

Although it was possible to identify potential optimum zones for sawtooth and plain edge waterfalls, as well as a single narrow jet in various acoustic settings (environments characterised by quiet or noisy noise levels ranging from 40 to 70 dB), findings discussed in Chapter 4 suggested that these water features tend not to be preferred for improving the soundscape perception in the context of relaxation, as they were negatively rated in the audio-visual tests. Additionally, a similar trend was found for the dome and foam fountains (ranked respectively 5th and 6th out of 10 features): these water features might be used in acoustic environments affected by RTN levels ranging from 40 to 60 dB, but their impact on soundscape perception might be more limited than the one provided by the preferred water features.

Overall, results showed that small to medium sized water features could be designed in view of relaxation in environments where road traffic noise levels range between 40 to 65 dBA. This suggests that higher sound pressure levels could be generated from larger sized water features which might be used in acoustic settings characterised by road traffic noise levels higher than 65 dBA. This confirmed the findings obtained by Brown and Rutherford (1994) and Nilsson *et al.* (2010), according to which large sized water features are effective for masking road traffic noise levels of 65-70 dBA. For example, a positive effect of water sounds generated from a large fountain with upward jets (2 m height and a flow rate of 1200 l/min) was found at 20-30 m around the structure in the presence of RTN levels of 65-70 dBA (Nilsson *et al.*, 2010), while the small fountain with upward jets (no extension and a flow rate of 30 l/min) tested in the work presented here, showed a ‘optimum zone’ extending only 1 m and 0 m from the feature when it was used over RTN levels of 65 and 70 dBA respectively. However, it is worth noting that the findings pointed out in the previous research (Nilsson *et al.*, 2010) were merely based on a quantitative analysis with respect only to the perceived loudness, meaning that this evaluation is not enough to understand perception of water sounds. For that reason, large sized water features might be efficient for masking high road traffic noise levels, but it is not yet clear how effective they are in improving the soundscape perception. Additionally, further research would be needed in view of understanding the impact of large sized water features on the soundscape quality, as well as evaluating the context for which they can have a positive influence on perception, e.g. large sized water features might be designed for vibrant environments such as urban squares, where they might contribute to excitement and freshness rather than relaxation.

In order to understand the effect of flow rate on the extension of the ‘optimum zone’, sound maps of water features with different flow rates were considered in the presence of RTN levels ranging from 40 to 70 dBA. Results showed a large increase in size of the ‘optimum area’ when increasing the flow rates of ST, CA, FTW and SHW (preferred water features in the audio-visual tests) for low levels of road traffic noise (40-50 dBA), while a slight increase was observed for all the water features tested in the presence of RTN levels ranging between 55 and 65 dBA. Furthermore, this analysis allowed understanding the effect of flow rate on the extension of the ‘optimum zone’ for the water features that are not able to produce high sound pressure levels (e.g. the natural stream used over 50-55 dBA). In the case of the natural stream used over RTN 50-55 dBA, the restricted ‘optimum zone’ can be expanded in size (~+6 m/ +2 m) by doubling its flow rate (2400 l/min to 4800 l/min). For the cascade with four steps (CA, 30 l/min) and the fountain with multiple upward jets (FTW, 30 l/min), the extension of the ‘optimum zone’ can be increased by increasing their flow rates when they are used over RTN levels of 60 dBA, but not for levels of 65 dBA. Although the size of the potential ‘optimum zones’ can be increased by increasing the flow rates, further research would be needed in order to investigate the effect of flow rates on the perception of these features, when used over RTN in the context of relaxation.

Additional analysis showed that the use of multiple (identical) water features located at different positions in the grid of study does not always expand the ‘optimum zone’ in specific acoustic settings. Among the preferred water features, the ‘optimum zone’ resulted to be still restricted to a very small area or completely absent even when more than one structure was installed (e.g. multiple natural streams used over RTN levels of 55-70 dBA or multiple cascades over RTN levels of 60-70 dBA). However, it was found that multiple streams operating under a flow rate higher than 2400 l/min might be used to promote relaxation when they are used over RTRN levels of 55 dBA. Furthermore, results showed that combinations of identical features such as cascades and fountains with multiple upward jets might be used in order to increase the extension of the optimum zone in the presence of RTN levels of 55. A similar trend was also found for multiple small holes waterfalls used at different positions over a RTN level of 60 dBA. These findings suggest that small to medium sized water features might not be really effective in improving relaxation in acoustic settings where levels of road traffic noise are higher than 60 dBA. This finding excludes waterfalls and single narrow jets which can generate sound pressure levels comparable to high RTN levels, but tend to be poorly rated in terms of relaxation.

Results in terms of sound maps including different types of water features suggested that combinations of preferred water features (CA, FTW and SHW) do not provide an effective design solution in view of improving relaxation in the presence of high levels of road traffic noise (RTN 65-70 dBA). However, these water features can be combined together in order to promote relaxation in an extended area affected by RTN 55 dBA. Furthermore, the use of fountains with multiple upward jets and small holes waterfalls represent the only design solution that is effective at generating a ‘optimum area’ in the presence of a RTN level of 60 dBA. Although the plain edge waterfalls tend not to be preferred, combinations of these features with small holes waterfalls also represent an effective solution for achieving sound pressure levels comparable to high levels of road traffic noise (RTN levels of 60-65 dBA). However, further research would be needed to demonstrate that these are beneficial in terms of relaxation, as the plain edge waterfall (PEW) sounds tend not to be liked.

Overall, results presented in this chapter have provided design solutions that can be used when choosing and installing small to medium sized water features in gardens or parks.

CHAPTER 8

A new framework of designable factors for the design of water features

8.1 Introduction

This chapter illustrates and provides a new conceptual framework for the design of water features in view of integrating acoustic criteria in the design process. At the end, conclusions are illustrated.

8.2 The design of water features

In the research presented here, a framework of designable factors for the water features is provided and shown in Figure 8.1. This systems was derived from a widespread examination of findings reported in the literature and related to the perceptual and physical assessment of water sounds (Table 2.8-9-10 of Chapter 2), and the definitions given by ISO 12913-1 (2014) (Figure 2.14 of Chapter 2), as well as the evaluation of findings obtained in the work presented here (Chapters 4-5–6-7). In Figure 8.1, the system aims at integrating the principles based on a soundscape approach (bottom of Figure 8.1) with the well-known criteria recognised by the landscape/architectural and engineering design points of view (top of Figure 8.1). This means incorporating soundscape properties of water features with designable factors, such as physical and technical properties (layout, type of installation, size, flow rate, impact material, finishing materials and components), aspects related to the environmental conditions (wind exposure, operating system, humidity control, background noise) and, aesthetic and functional properties (visual appeal, focal point, native habitat and the intended use of the surrounding areas) at the very early stage of a design process. For example, while defining the type of installation for a specific environment, it is important to take into account that preferences for a type of water feature cannot be only influenced and related to the designer's style: it will be crucial to consider also the acoustic properties of that specific type of installation and the acoustic environment where this will be installed, as well as its perception experienced by people living in that environment. Soundscape criteria are defined here as properties related to water sounds, the acoustic environment, subjective perception and finally the interpretation of the perception of waterscapes. Furthermore, the complex interaction between all these factors should be evaluated by considering the

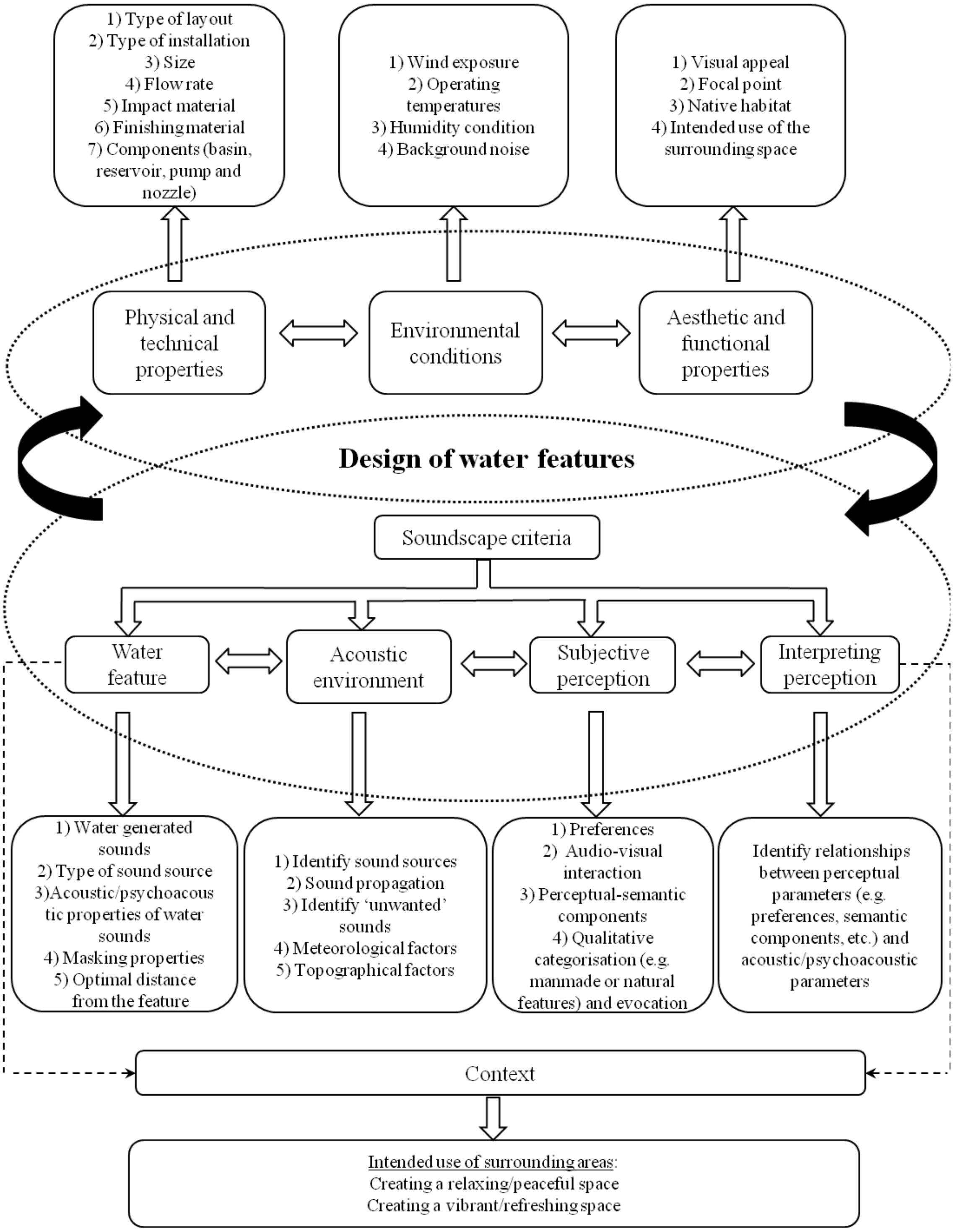


Figure 8.1 A new framework of designable factors for the design of water features. Integrating soundscape criteria with well-known parameters based on landscape/architectural/engineering approaches.

context referring to the intended use of the space where the water features will be located: designing an environment in view of relaxation/peacefulness (e.g. gardens or parks, green areas in general) or vibrating/refreshing spaces such as urban squares. The study of the acoustic environment refers to the identification of sound sources and the effects on sound propagation such as meteorological conditions and topographical factors, as well as the identification and characterisation of 'unwanted' sound which might be totally/partially masked by introducing 'wanted' sounds such as water sounds. After that, the properties associated to water features take into account different aspects. Firstly, the physical properties of water features should be considered by evaluating the physical phenomenon of water generating sounds and the type of sound source with respect to design factors, such as impact material, height of falling water, waterfalls' edge conditions, and flow rate. The analysis of acoustic/psychoacoustic properties of water sounds and their masking characteristics should also be investigated in view of revealing a relationship with subjective perception. Furthermore, the evaluation of the optimal distances from the water features where perception can be improved should be conducted considering quantitative criteria based on results of preferences and acoustic characteristics of water sounds. Additionally, the analysis of the perception of water sounds takes into account the identification of audio and visual preferences, the evaluation of audio-visual interaction and the assessment of semantic perceptual components, as well as the evaluation of the categorisation and evocation of water sounds that might have an effect on sound perception. With regard to the non-acoustical factors, previous research pointed out that socio-cultural, demographic factors have no significant influence on soundscape perception (Yu and Kang, 2008). In particular, the effect of social-demographic/cultural factors has been proved to be insignificant for the perception of water sounds (Yu and Kang, 2010) (Galbrun and Ali, 2013), perhaps because water plays an important role in urban soundscape and it is enjoyed by everybody (Yu and Kang, 2010). However, subjective perception of water sounds might depend on individual factors (experiences, memories, etc.) related to human beings (Galbrun and Ali, 2013). Finally, the interpretation of waterscapes' perception consists of evaluating and identifying the relationships between perceptual parameters such as preferences in uni-modal and bi-modal conditions, semantic components, and objective indices such as acoustic/psychoacoustic parameters. All these properties should be studied individually, and the evaluation of inter-relationships between them should then be considered. The framework presented in this research provides an innovative tool for water features' design by highlighting the importance of integrating soundscape criteria that should be considered at the very early stage of the design process in urban and landscape planning and design.

8.3 Conclusions

Although several efforts have been made in recent researches towards investigating the acoustic and perceptual properties of water generated sounds, there are at present no specific guidelines for the soundscape design of water features. In this context, a new design framework of designable factors for water features' design has been proposed and illustrated: this suggests how to integrate soundscape criteria with well-known aspects of water features recognised by landscape/architectural and engineering approaches, and this also defines which are the different acoustic aspects that need to be considered in the design process.

The literature review, shown in Chapter 2, has led to define the crucial criteria which can be considered for the design of water features based on a soundscape approach according to which acoustical and non-acoustical features should be related to the subjective perception of sounds. These soundscape criteria has been derived from findings obtained in this current work, as well as those presented in previous studies of the literature, as well as the definitions provided by ISO 12913-1 (2014).

This framework suggests the integration of principles based on a soundscape approach with the well-known criteria recognised by the landscape/architectural and engineering approaches: soundscape criteria should be associated to the aesthetic/functional and physical/technical properties of water sounds as well as the properties related to environmental conditions. Furthermore, soundscape criteria have been defined here as the properties related to the acoustic environments, properties of water features referring to acoustic and visual aspects, subjective perception and finally the interpretation of the perception of waterscapes, and the complex interaction between all these factors relating to the context and the intended use of the space (e.g. designing environments in view of relaxation/peacefulness (gardens or parks, green areas in general) or vibrating/refreshing spaces such as urban squares).

CHAPTER 9

Conclusions

9.1 Introduction

This chapter illustrates the main findings obtained from the research. A summary of conclusions is given for each chapter, and this is followed by a description of the impact of research. Suggestions for future work are described at the end of the chapter.

9.2 Conclusions

This research examined the soundscape design of water features used over road traffic noise, with particular attention given to the audio-visual impact on preferences, the semantic audio assessment, as well as the perceptual categorisation and evocation of water sounds. Furthermore, sound maps were developed to identify the effectiveness of different water features in promoting relaxation where road traffic noise is audible. The work had the objective to perceptually characterise water sounds, rather than examining their masking properties. Additionally, the thesis aimed at providing evidence-based design solutions.

Chapter 2 provided a review of the literature by highlighting the main findings that were relevant to the research. These findings were critically discussed in order to identify the knowledge gaps, as well as to help give justifications for the research presented here and define its objectives. The literature highlighted that the approaches used for water features' design have mainly focused so far on aesthetic/functional aspects. Considering that water sounds have often been identified as the best sounds for enhancing the urban soundscape in view of reducing stress and improving quality of life (Kang, 2007) (Jeon *et al.*, 2010), there is a need to include acoustic criteria at the early stage of the design process, and find a connection with the well-known designable aspects of water features. In this context, the soundscape approach (physical and mental perception of the acoustic environment) has provided an innovative tool for designing water features. The literature showed that previous research has advanced the better understanding of the acoustic use of water generated sounds for masking annoying noise, but there is still limited knowledge relating to the perceptual assessment of water features and in particular to the effects of audio and visual design. Furthermore, the need to develop a better understanding on the masking effects of water sounds used over road traffic noise was pointed out.

Chapter 3 described the methodology used for the research. Initially, the water features examined in the research were illustrated in details, including the test structure and procedures that were used by Galbrun and Ali (2013) in view of constructing and testing the features used in the present research. Details of the acoustic and visual stimuli were then given for the ten waterscapes tested in the research. Finally, the methodology used for the perceptual assessment of water features was also presented, including a description of the statistical methods used for data analysis.

Chapter 4 illustrated findings obtained from the audio-visual tests that aimed at identifying the preferred water sounds and visual displays of water features for improving relaxation within gardens and parks where road traffic noise is audible, as well as investigating the relationship between acoustic/psychoacoustic parameters and subjective perception of water sounds. Results in terms of audio-only preferences pointed out that natural shallow stream sounds tend to be preferred over fountain sounds, which are in turn preferred over waterfall sounds, confirming the findings obtained by Galbrun and Ali (2013). Paired comparisons highlighted the inter-dependence between uni-modal (audio-only or visual-only) and bi-modal (audio-visual) perception, suggesting that equal attention should be given to the design of both stimuli. Audio-visual analysis showed that visual stimuli had a positive effect on sound perception in four out of ten cases, while a negative effect was found for six cases. These results did not mean that some visual stimuli are detrimental, but simply that some features benefit more than others from a visual stimulus (as an increase in preference scores for some features necessarily led to a decrease for other features, because of the paired comparison method used). Results pointed out that the subjective perception in bi-modal conditions was affected by the uni-modal sensorial patterns, as significant correlations were found in most cases between audio-visual preferences and both audio-only and visual-only preferences. This suggested that a single stimulus was rarely dominant in driving waterscapes' perception. This finding was also confirmed by results obtained from further analysis made in terms of differences in responses: both auditory and visual stimuli tended to be equally important for preferences. Results from hierarchical cluster analysis showed no significant variations in preferences. However, some water features (large jet (LJT) and waterfall with an edge made of small holes (SHW)) were either liked or disliked, although this tended to be unusual (observed only for two features out of ten). Finally, a weak association was found between perception of water sounds and acoustic/psychoacoustic parameters of the corresponding stimuli.

Chapter 5 highlighted results obtained from the semantic differential test with the aim of identifying the principal semantic components affecting the perception of water sounds, as well as investigating the relationship between semantic components and acoustic/ psychoacoustic parameters, as well as the preferences of water sounds. A principal component analysis identified three principal components ("emotional assessment", "sound quality" and "envelopment and temporal variation") affecting sound perception for the ten waterscapes considered. "Emotional assessment" was related to the emotional attributes of sounds, and included relaxation, naturalness, freshness, and familiarity. "Sound quality" and "envelopment and temporal variation" were related to the psychoacoustical and physical properties of sounds. "Sound quality" consisted of perceived sharpness, perceived roughness and speed, whilst "envelopment and temporal variation" included envelopment and temporal variation. Results showed that "emotional assessment" was positively correlated with preferences from the audio-only tests, whilst a negative correlation was found between "sound quality" and preferences. Additionally, no correlation was found between "envelopment and temporal variation" and preferences. A logit binary model pointed out that "emotional assessment" is the only significant predictor for driving preferences. Overall, results suggested that this represents the most important component affecting the perception of water sounds perception. Within the "emotional assessment", naturalness, relaxation, and freshness showed significant correlations with audio-only preferences, while low scores of perceived sharpness and perceived roughness provided significant negative correlations within the "sound quality" component. Additionally, subjects were unable to correctly assess the sharpness, roughness and temporal variations of water sounds, as no correlations were found between physical parameters and their corresponding perceptual descriptors. Furthermore, a weak association was found between semantic components of water sounds and their corresponding acoustic/psychoacoustic parameters. However, some semantic attributes (speed and envelopment) were significantly correlated with acoustic (L_{A10}-L_{A90}) and psychoacoustic (sharpness and roughness) parameters.

Chapter 6 illustrated the main findings obtained from the categorisation and evocation of water sounds used over road traffic noise in view of understanding how these aspects can affect preferences of water sounds. The analysis of qualitative sound categorisation (*waterfall* vs. *fountain* vs. *natural stream* vs. *none of them*) pointed out that natural stream sounds tend to be more easily identifiable, while it is difficult to identify waterfall and fountain sounds, although waterfalls were more easily identifiable than fountains. No significant correlations were found between preferences and the perceived categories *waterfall* and *fountain*. Results of correlations showed that perceived waterfall was correlated with temporal variation in level and roughness, whilst perceived fountain correlated significantly with temporal variation in level. However, these relationships did not provide a clear explanation in finding a unique relationship between perceived categories and acoustic/psychoacoustic parameters. Evocation results indicated that single upward jets (NJT and LJT) were evaluated by most subjects as manmade sounds evocative of water taps, and these tended not to be liked, as a negative correlation was found between manmade evocation and audio-only preferences (although this correlation was not significant): this can probably justifies their low auditory rating. The same trend was observed between rainfall evocation and preferences: water sounds evocative of rainfall tended not to be preferred, as the correlation was negative but not statistically significant. Results also indicated that evocation of manmade sounds was significantly correlated with roughness, whilst no correlation was found between evocation of rainfall and acoustic/psychoacoustic parameters. Overall, these results suggested that auditory evocation might be strictly associated to the overall perception of water features rather than to their auditory preferences. Finally, visual categorisation results provided a further insight into the impact of audio-visual impact on the perception of waterscapes. These indicated that the displays of water features associated to natural looking structures tended to increase audio-visual preferences (although mean differences were statistically significant only for the natural stream (ST)). However, the exception represented by the manmade looking cascade (CA) suggested that well designed artificial features can be visually pleasing.

Chapter 7 illustrated sound maps of water features used over road traffic noise. This analysis aimed at examining the sound pressure level effectiveness of small to medium sized water features used over different ranges of road traffic noise levels, within the context of relaxation, as well as identifying the optimal distances from the water features tested where relaxation can be promoted. Results obtained from mapping water generated sounds indicated that waterfalls tend to be louder than fountains, jets and cascades, as already pointed out by Galbrun and Ali (2013). Furthermore, results of sound maps for water features operating under different flow rates showed that the effect of flow rate is less noticeable for waterfalls, whilst larger variations in sound pressure levels were found for fountains (as previously highlighted by Galbrun and Ali (2013)). Three acoustic zones (‘water sounds dominant zone’, ‘optimum zone’ and ‘RTN dominant zone’ (RTN: road traffic noise)) were defined here as the areas where potential relaxation/pleasantness can be promoted around the water features used over different ranges of road traffic noise levels. In the ‘water sounds dominant zone’, water sounds are louder than road traffic noise. The ‘optimum zone’ was defined as the area where water sound levels are similar or not less than 3 dB below road traffic noise, corresponding to the levels which were found to be preferred (You *et al.*, 2010) (Jeon *et al.*, 2012) (Galbrun and Ali, 2013). In the ‘RTN dominant zone’, water sound levels are lower than the RTN level minus 3 dBA. Results of acoustic zones’ mapping indicated that the natural stream (ST) tends to be most effective for promoting relaxation when it was used over road traffic noise levels of 40-45 dBA. The fountain with multiple upwards jets (FTW) and the small holes waterfall (SHW) could be used over RTN levels ranging between 40-65 dBA, whilst the cascade with four steps (CA) could be used over RTN levels ranging between 40-60 dBA. All these features tended to improve the soundscape perception, having been positively rated in the audio-visual tests (1st to 4th ranking positions respectively). Furthermore, sawtooth and plain edge waterfalls (SEW and PEW) as well as the narrow jet (NJT) were effective at generating potential ‘optimum zones’ over a wider range of RTN levels (40-70 dBA), but these structures tended to have a limited effect for improving soundscape perception (i.e., low ranking in preference scores). It is also worth mentioning that the analysis of acoustic zones allowed identifying the optimal distances from all the water features examined. Additional analysis indicated that the use of multiple (identical) water features does not always expand the ‘optimum zone’ in acoustic settings characterised by RTN levels higher than 60 dBA. Overall, results highlighted that small to medium sized water features (individual or combined features) could be used in environments where RTN levels are equal or lower than 65 dBA in view of improving relaxation and peacefulness. However, these findings are limited to results of sound maps that need to be experimentally validated in the field. This finding suggested that sound pressure levels comparable to RTN levels higher than 65 dBA can be mainly generated by water features which have larger dimensions than those tested in the features presented in this work. This was confirmed by previous research (Nilsson et al, 2010) (Axelsson *et al.*, 2014) which examined large sized water features located in urban settings, although it is not yet clear how effective these are in enhancing the soundscape perception.

Chapter 8 illustrated a new framework of designable factors for the design of water features, and this was derived by reviewing previous research and considering main findings obtained from the research presented here.

9.3 Impact of the research

In view of identifying "harmonised" criteria for the soundscape design of water features, the main findings obtained in this research might be used by urban planners, landscape architects and acoustic engineers in view of integrating soundscape designable criteria with the well-known aesthetic/functional aspects of water features for future urban planning and design. Ultimately, the findings of research should lead to evidence-based design of water features, in view of providing innovative solutions to noise annoyance, compared to the traditional noise control engineering methods.

9.4 Suggestions for future research

In this section, suggestions for future research are illustrated, based on the findings highlighted in this work and previous research.

The research presented here examined the perceptual assessment of small to medium sized water features used over road traffic noise. Laboratory preference tests were carried out using water sounds combined with road traffic noise characterised by low temporal variability (road traffic noise from a motorway). Previous research (De Coensel *et al.*, 2011) pointed out that sound perception can vary depending on the characteristics of background noise, such as road traffic noise with low (e.g. traffic from freeway or major road) or high (e.g. traffic from minor road) temporal variability. In particular, De Coensel *et al.* (2011) highlighted that adding water sounds can improve aural perception of soundscapes dominated by road traffic noise, only if the latter is characterised by low temporal variability. For that reason, it would be interesting to evaluate how the perception of water features can vary in the presence of different types of road traffic noise. Audio-visual tests could be repeated for the waterscapes examined when they are combined with road traffic noise with high temporal variability (e.g. noise from a city street), and results could then be compared with those obtained in this thesis.

The research presented here pointed out that natural shallow streams tend to be preferred to fountains and waterfalls, and these were able to generate lower sound pressure levels than those produced by the other features. Additionally, the installation of this type of water feature needs large spaces and requires large volumes of water. For that reason, further research would be needed in order to understand the cost of this type of installation and its convenience when this is incorporated into a garden or park in comparison to the other water features tested in this thesis. Furthermore, it would be also interesting to evaluate the economic impact of designing water features as innovative solutions in comparison to those of traditional engineering solutions such as noise barriers.

Additionally, it would also be interesting to investigate how perception of semantic properties of water sounds, as well as their categorisation and evocation vary in the presence of different road traffic noise. Previous research indicated that the principal semantic components can have a different weight in affecting sound perception depending on the background noise (road traffic noise). De Coensel *et al.* (2011) pointed out that water sounds can improve the "pleasantness" of soundscape for road traffic noise from major road, and "eventfulness" of sounds in the presence of road traffic noise from a freeway. Jeon *et al.* (2010) pointed out that "freshness" had more weight at low levels of road traffic noise, while "calmness" and "vibrancy" had more weight on perception for higher road traffic noise levels. A similar trend was found by Hong and Jeon (2013) who indicated the "overall quality" as an important component at low levels of road traffic noise, while "pleasantness" had more weight in the presence of high levels of road traffic noise. Semantic differential tests could be repeated in order to evaluate the weight of the three principal components found in the research presented here under different background noise conditions. Furthermore, results obtained here suggested that auditory evocation might be strictly associated to the overall perception of water features rather than to their auditory preferences. For that reason, qualitative categorisation and evocation tests could also be repeated for all the waterscapes tested in view of investigating how the overall perception of water features vary with different background noise.

The main findings presented in the current work were based on results of the preferences of water features obtained from laboratory tests. Further research could be conducted to determine whether there are any differences in findings between laboratory and field (real world) conditions. Water features could be identified in real environments as similar as possible to those tested in the laboratory, although it might be difficult to find a similar range of features and road traffic noise conditions. Soundwalks could then be carried out in order to understand how auditory and visual perception can vary when moving from areas without water features to areas with water features. Semantic differential test could also be undertaken in view of identifying qualitative perception of water features in a real environment while moving along a water feature.

Although current and previous (Galbrun and Ali, 2013) findings indicated a weak association between psychoacoustic parameters of water sounds and their corresponding perceptual preferences, further research could be carried out in order to investigate the spatial distribution of psychoacoustic parameters for the water sounds tested. Genuit *et al.* (2008) suggested psychoacoustic mapping as an innovative tool to characterise sound sources for soundscape applications. The authors indicated that the spatial distribution of sharpness and roughness was not strongly varying across their surveyed places, while loudness decreased significantly with increasing distances from the sources (Genuit *et al.*, 2008). Spots measurement of binaural recordings could be undertaken for water features in real (field) conditions at different distances from the sources. The recordings could be used to compute psychoacoustic parameters and develop “sharpness maps”, “roughness maps”, “loudness maps” and “fluctuation strength maps” for each type of water feature. This would allow understanding the characteristics of psychoacoustic parameters such as loudness, roughness and sharpness as a function of distance from the sound source.

Results obtained here in terms of sound maps indicated that the size of potential ‘optimum zones’ can be increased using water features operating under different flow rates, but further research would be needed in order to investigate the effect of flow rates on the perception of these water features.

Furthermore, results showed that combinations of preferred water features (CA, FTW and SHW) do not provide an effective design solution in view of improving relaxation for settings with road traffic noise levels ranging from 65 to 70 dBA. Although plain edge waterfall (PEW) tended not to be preferred, combinations of this feature with small holes waterfall (SHW) represented an effective solution in increasing the size of the ‘optimum zone’ when they were used over high levels of road traffic noise. For that reason, further research would be needed to evaluate the effectiveness of these waterfalls in promoting relaxation in noisy settings. This suggests that perceptual preference tests could be repeated considering combinations of multiple water features under different road traffic noise conditions.

Results obtained in terms of optimal distances from water features where relaxation can be promoted, could be validated by further research in the field. For example, preferred distances could be tested in real conditions where a natural stream is located in a suburban green area where road traffic noise is ranging between 40-45 dBA. In this case, subjects could be seated at 8-15 m from the natural stream from which he/she can hear and see the water feature in the presence of road traffic noise, and optimal distances should be identified in the context of relaxation.

Additionally, it would be interesting to experimentally validate the sound maps obtained for all the different type of water features tested, and further research would be needed to investigate why the propagation model used for the line source did not perfectly predict the measured propagation from the natural shallow stream.

Ren and Kang (2015) also indicated that the auditory perception of flowing water (e.g. sound from a lake) does not change for both small and large visual distance from the waterscape. It would be interesting to evaluate how the factor “visual distance” can affect auditory perception: audio-visual tests could be repeated by considering visual stimuli that consisted of the water features placed on the same natural background but at different visual distances.

The present work was carried out in view of improving relaxation and peacefulness where road traffic noise is audible. This connects with research related to restoration which helps to recover from stress and sensory overload (Hartig *et al.*, 2003) (Kaplan, 1995) (Ulrich, 1983). In the context of protecting quiet areas inside agglomerations and in countryside as identified by the Environmental Noise Directive (END) (European Communities, 2002), several studied examined restoration in soundscape research (Hartig *et al.*, 2003) (Brambilla and Maffei, 2006) (Botteldooren and De Coensel, 2006) (Gidlöf-Gunnarsson and Öhrström, 2007) (Payne, 2008) (Irvine *et al.*, 2009) (Hartig, 2010) (Botteldooren *et al.*, 2011) (Payne, 2013). Further research could be conducted in view of investigating the restorative effects of the waterscapes tested in this work. This could be limited to the water features that resulted to be preferred in terms of relaxation, and their impact on reducing health effects due to noise exposure could be evaluated using measures of physical stress such as blood pressure (Hartig *et al.*, 2003) and brain activity using a neuro-headset (EEG systems, electroencephalography).

Davies *et al.* (2009) indicated that principal semantic components affecting auditory perception might be validated using tests which help to see what physically changes in the body and brain, such as a fMRI (Functional Magnetic Resonance Imaging) scanning. In the fMRI scanner, it was found that passive listening to soundscapes engages several regions of the brain: the difference between soundscapes rated neutral and high or low on factors such as “calmness” and “pleasantness” showed activity in the left and right amygdale that is a brain region associated with processing emotion (almond-shape set of neurons located deep in the brain's medial temporal lobe) (Davies *et al.*, 2009). These tests could be used in further research to validate the perceptual descriptors found in this research from a physiological point of view.

In this thesis, sound maps were developed by considering quantitative criteria obtained from perceptual preference tests. It would be interesting for further research to develop sound maps relating to the semantic descriptors of the water sounds tested: this would allow investigating the spatial distribution of "emotional assessment", "sound quality" and "envelopment and temporal variation" for specific water features. This could be carried out using results obtained from field surveys (e.g. soundwalks along a water feature, as mentioned above), and trying to develop qualitative sound maps as suggested by Boubezari and Coelho (2004).

Last but not least, findings from sound maps indicated that small to medium sized water features could be designed in view of relaxation in environments where road traffic noise levels range between 40 to 65 dBA. This suggested that higher sound pressure levels could be generated from larger sized water features which might be used in acoustic settings characterised by road traffic noise levels higher than 65 dBA. Previous studies indicated that a large fountain with upward jets can be effective for masking high level of road traffic noise (Nilsson *et al.* 2010) (Axelsson *et al.*, 2014), but there is still limited knowledge on how effective such fountains are in improving the soundscape perception. Further research is therefore needed in view of developing a better understanding about the impact of large sized water features on soundscape quality, as well as for evaluating the context for which they can be designed. For example, large sized water features might be designed for vibrant environments such as urban squares, where they might contribute to excitement and freshness rather than relaxation.

REFERENCES

Ali, T.T. (2012). *Acoustical design of water features and their use for road traffic noise masking*. PhD Thesis, Heriot Watt University, October 2012, Edinburgh.

Allison, P., (2013). *What's the Best R-Squared for Logistic Regression*, Statistical Horizons.

AMC Air Mobility Command. (1999). *Air Mobility Command Publications, Landscape design guide*. Directorate of Civil Engineering, USA, 1999.

Axelsson, O. (2010a). *Designing soundscape for sustainable urban development*. Sustainable Urban Development. 30 September-1 October, Stockholm, Sweden, 2010.

Axelsson, O. (2010b). *Standardization in soundscape research*. Proceeding of the DAGA 2010, 15-18 March 2010, Berlin, Germany.

Axelsson, O., Nilsson, M. E., and Berglund, B. (2010). *A principal components model of soundscape perception*. The Journal of the Acoustical Society of America, 128(5), 2836–2846, 2010.

Axelsson, O., Nilsson, M. E., Hellström, B., and Lundén, P. (2014). *A field experiment on the impact of sounds from a jet-and-basin fountain on soundscape quality in an urban park*. Landscape and Urban Planning, **123**, 49–60, 2014.

Booth, N. K. (1989). *Basic Elements of Landscape Architectural Design*. Waveland Press, Long Grove, USA.

Botteldooren, D., and De Coensel, B., (2006). *Quality labels for the quiet rural soundscape*. Proceeding of InterNoise 2006, 3-6 December 2006, Honolulu, Hawaii, USA.

Botteldooren, D., Lavandier, C., Preis, A., Dubois, D., Aspuru, I., Guastavino, C., Brown, L., Nilsson, M., and Andringa, T.C. (2011). *Understanding urban and natural soundscapes*. Proceeding of Forum Acusticum 2011, 26 June-1 July 2011, Aalborg, Denmark.

Boubezari, M., and Coelho, J. L. B. (2004). *The limit of audibility as a perceptive criterion for qualitative maps*. Proceeding of Acustica 2004, 13-17 September 2004, Guimarães, Portugal.

Brambilla, G. and Maffei, L. (2006). *Responses to Noise in Urban Parks and in Rural Quiet Areas*. Acta Acustica united with Acustica, **92**, 881–886, 2006.

Bramley, T., (2007). *Techniques for monitoring the comparability of examination standards*, Chapter 7: Paired Comparison Methods. Qualifications and Curriculum Authority, London.

Brown, T.C. and Peterson, G.L., (2009). *An Enquiry into the Method of Paired Comparison: Reliability, Scaling, and Thurstone's Law of Comparative Judgment*. Technical Report, 1–104, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2009.

Brown, A. L., and Rutherford, S. (1994). *Using the Sound of Water in the City*. Landscape Australia, **2**, 103–107, 1994.

Brown, A. L., and Muhar, A. (2004). *An approach to the acoustic design of outdoor space*. Journal of Environmental Planning and Management, **47(6)**, 827–842, 2004.

Brown, A. L., Kang, J., and Gjestland, T. (2011). *Towards standardization in soundscape preference assessment*. Applied Acoustics, **72(6)**, 387–392, 2011.

Burmil, S., Daniel, T. C., and Hetherington, J. D. (1999). *Human values and perceptions of water in arid landscapes*. Landscape and Urban Planning, **44(2–3)**, 99–109, 1999.

Burns, R.P. and Burns, R. (2008). *Business research methods and statistics using SPSS*. Sage, London.

Cabrera, D., Ferguson, Rizwi, F., S., and Schubert, E., (2008). *Psysound 3: a program for the analysis of sound recordings*. Journal of the Acoustical Society of America, **123(5)**, 3247, 2008.

Cain, R., Jennings, P., and Poxon, J. (2011). *The development and application of the emotional dimensions of a soundscape*. Applied Acoustics, **74(2)**, 232-239, 2011.

Carles, J., Bernáldez, F., and De Lucio, J. (1992). *Audio-visual interactions and soundscape preferences*. Landscape Research, **17(2)**, 52–56,1992.

Carles, J. L., López Barrio, I., and De Lucio, J. V. (1999). *Sound influence on landscape values*. Landscape and Urban Planning, **43(4)**, 191–200, 1999.

CIBSE, (2004). *CIBSE Guide G: Public Health Engineering. Part 8: water features and fountains.* The Chartered Institution of Building Services Engineers, London, United Kingdom.

COST Action TD0804 (2013). *Soundscape of European cities and landscapes*. COST Office through Soundscape-COST, Oxford, UK.

Davies, W. J., Adams, M. D., Bruce, N. S., Marselle, M., Cain, R., Jennings, P., and Plack, C. J. (2009). *The positive soundscape project*: *A synthesis of results from many disciplines*. Proceeding of InterNoise 2009, 1161–1166, 23-26 August 2009, Ottawa, Canada.

Davies, W. J., Bruce, N. S., and Murphy, J. E., (2014) . *Soundscape reproduction and synthesis* Acta Acustica United with Acustica, **100(2)**, 285-292(8), 2014.

De Coensel, B., and Botteldooren, D. (2006). *The quiet rural soundscape and how to characterize it*. Acta Acustica United with Acustica, **92(6),** 887–897, 2006.

De Coensel, B., Bockstael, A., Dekoninck, L., Botteldooren, D., Schulte-Fortkamp, B., Kang, J., and Nilsson, M. E. (2010). *Application of a model for auditory attention to the design of urban soundscapes*. Proceeding of the 1st EAA-EuroRegio 2010-Congress on Sound and Vibration, 15-18 September 2010, Ljubljana, Slovenia.

De Coensel, B., Vanwetswinkel, S., and Botteldooren, D. (2011). *Effects of natural sounds on the perception of road traffic noise*. The Journal of the Acoustical Society of America, **129(4)**, EL148–EL153., 2011.

DEFRA (2011). *The economic value of quiet areas*. Department for Environment Food & Rural Affairs of Environmental Services, 2011.

Department of Environmental Services (2010). *Quietening open spaces. Toward suistainable soundscape for the City of London*. URS Scott Wilson, City of London.

Downing, M. F. (1977). *Landscape construction*. Spon, London.

Dreiseitl, H., and Grau, D. (2005). *New Waterscapes: Planning, Building and Designing with Water*. Walter de Gruyter, Berlin, Germany.

Durlach, N., Mason, C., Kidd, G., Arbogast, T., Colbum, H.S., and Shinn-Cunningham, G., (2003*). Note on informational masking (L)*. The Journal of the Acoustical Society of America, **113**, 2984–2987, 2003.

Dykstra, T. (2007). *Aqua house: A house design that explores the possibility of integrating architecture and water, technically and aesthetically*. Unitec New Zeland, 2007.

EPA, (1974). *Information on levels of environmental noise requisite to protect public health and welfare with adequate margin of safety*. European Environment Agency Office, Washington.

European Communities (EC) (2002). *DIRECTIVE 2002/49/CE of the European Parliament and the Council of 25 June relating to the assessment and management of environmental noise.* Official Journal of the European Communities, 45, 12–25.

European Environment Agency (EPA) (2014). *Noise in Europe 2014-EEA Report No 10/2014.* Luxembourg.

Fastl, H., 2002. *From psychoacoustics to sound quality engineering*. Proceeding of the Institute of Acoustics 2002, 14-18 May 2012, Hong Kong.

Fastl, H. (2005). *Recent developments in sound quality evaluation*. Proceeding of Forum Acusticum, 1647–1653, 29 August -2 September 2005, Budapest, Hungary.

Fastl, H. (2006). *Psychoacoustic basis of sound quality evaluation and sound engineering*. Proceeding of ICSV13 - The 13th International Congress on Sound and Vibration, 324–345, July 2006, Vienna, Austria.

Fastl, H. and Zwicker, E., (2006). *Psychoacoustics*. *Facts and models*. Springer-Verlag New York Inc, New York.

Fiebig, A., Acloque, V., Basturk, S., Di Gabriele, M., Horvat, M., Masullo, M., Pieren, R., Voigt, K.S., Yang, M., Genuit, K., and Schulte-Fortkamp, B., (2010). *Education in Soundscape-A seminar with young scientists in the COST Short Term Scientific Mission "Soundscape-Measurement, Analysis, Evaluation"*. Proceeding of ICA 2010, 23-27 August 2010, Sydney, Australia.

Field, A. (2009). *Discovering Statistics Using SPSS*, Sage Publications Inc., London.

Fraley, C., and Raftery, A. E., (2000). *Model-based clustering, discriminant analysis, and density estimation*. Techincal Report No. 380, Department of Statistics, University of Washington, Seattle, WA 98195-4322, USA, October 2000.

Fry, A. (1988). *Noise control in building services*. Pergamon Press,Oxford.

Fowler, M. D. (2013). *Soundscape as a design strategy for landscape architectural praxis*. Design Studies, **34(1)**, 111–128, 2013.

Galbrun, L., and Ali, T. T. (2013). *Acoustical and perceptual assessment of water sounds and their use over road traffic noise*. The Journal of the Acoustical Society of America, **133(1)**, 227–237, 2013.

Genuit, K., Schulte-Fortkamp and B., Fiebig, A., (2008). *Psychoacoustic mapping within the soundscape approach*. Proceeding of InterNoise 2008, 594–606, October 2008, Shangai, China.

Gidlöf-Gunnarsson, A., and Öhrström, E., (2007). *Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas*. Landscaspe Urban Planning, **83**, 115–126, 2007.

Gramann, J. (1999). *The effect of mechanical noise and natural sound on visitor experiences in units of the national park system*. NPS Social Science Research Review, I(1), 1999.

Guillén, J. D., and López Barrio, I. (2007). *The soundscape experience*. Proceeding of ICA 2007, The 19th International Congress on Acoustics, 9-12 September 2007, Madrid, Spain.

Hartig, T., Evans, G.W., Jamner, L.D., Davis, D.S. and Gärling, T., (2003). *Tracking restoration in natural and urban field settings*. Journal of Environmental Psychology, **23**,109–123, 2003.

Hartig, T. (2010). *The Restoration Perspective in Soundscape Research*, Report of Institute for Housing and Urban Research and Department of Psychology, Uppsdala, Sweden, 2010.

Hong, J. Y., Lee, P.J., and Jeon, J. Y., (2010). *Evaluation of urban soundscape thorough soundwalking*. ICA 2010, August 2010, Sydney, Australia.

Hong, J. Y., and Jeon, J. Y. (2013). *Designing sound and visual components for enhancement of urban soundscapes*. The Journal of the Acoustical Society of America, 134(3), 2026–36, 2013.

Hong, J. Y., and Jeon, J. Y. (2015). *Influence of urban contexts on soundscape perceptions: A structural equation modeling approach*. Landscape and Urban Planning, **141**, 78–87, 2015.

Hopwood, R. (2004). *Fountains and Water Features*. Osprey Publishing, Buckinghamshire, UK.

Irvine, K.N., Devine-Wright, P., Payne, S.R., Fuller, R.A., Painter, B., and Gaston, K.J., (2009). *Green space, soundscape and urban sustainability: an interdisciplinary, empirical study*. Local Environment, **14**, 155–172, 2009.

ISO 1996-2 (1987). *Acoustics - Description and Measurement of Environmental Noise*. International Organization for Standardization, Genève, Switzerland.

ISO 9613-1. (1993). *Acoustics. Attenuation of sound during propagation outdoors. Part 1: Calculation of the absorption of sound by the atmosphere*. International Organization for Standardization, Geneva.

ISO 9613-2. (1996). *Acoustics-Attenuation of sound during propagation outdoors-Part2: General method of calculation*. International Organization for Standardization, Genève, Switzerland.

ISO 226 (2003). *Specification for normal equal-loudness level contours for pure tones under free-field listening conditions*. International Organization for Standardization, Genève, Switzerland.

ISO/TS 15666 (2003). *Acoustics-Assessment of noise annoyance by means of social and socio-acoustic survey*. International Organization for Standardization, Genève, Switzerland.

ISO 12913-1 (2014). *Acoustics-Soundscape Part1: Definition and conceptual framework*. International Organization for Standardization, Genève, Switzerland.

Jakovljevic, B., Paunovic, K., and Belojevic, G. (2009). *Road-traffic noise and factors influencing noise annoyance in an urban population*. Environmental International, **35**, 552–556, 2009.

Jeon, J. Y., Lee, P. J., You, J., and Kang, J. (2010). *Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds*. The Journal of the Acoustical Society of America, **127(3)**, 1357, 2010.

Jeon, J. Y., Lee, P. J., Hong, J. Y., and Cabrera, D. (2011). *Non-auditory factors affecting urban soundscape evaluation*. The Journal of the Acoustical Society of America, **130(6),** 3761–3770, 2011.

Jeon, J. Y., Lee, P. J., You, J., and Kang, J. (2012). *Acoustical characteristics of water sounds for soundscape enhancement in urban open spaces*. The Journal of The Acoustical Society Of America, **131(3)**, 2101–2109, 2012.

Jeon, J. Y., Hwang, I. H., and Hong, J. Y. (2014). *Soundscape evaluation in a Catholic cathedral and Buddhist temple precincts through social surveys and soundwalks*. The Journal of the Acoustical Society of America, **135(4)**, 1863–74, 2014.

Jian, G., Jiang, L., and Hongfeng, G. (2005). *Research on Soundscape of Urban Open Spaces for the Practical Design*. Proceeding of InterNoise 2005, August 2005, Rio de Janeiro, Brazil.

Kang, J., (2007). *Urban Sound Environment*. Taylor and Francis, New York.

Kang, J., (2010). *From understanding to designing soundscapes*. Frontiers of Architecture and Civil Engineering in China, **4(4)**, 403–417, 2010.

Kang, J., and Zhang, M. (2010). *Semantic differential analysis of the soundscape in urban open public spaces*. Building and Environment, 45(1), 150–157, 2010.

Kaplan, S. (1987). *Aesthetics, Affect, and Cognition Environmental Preference from an Evolutionary Perspective*. Environment and Behaviour, **19**, 3–32, 1987.

Kaplan, S. (1995). *The restorative benefits of nature: Toward an integrative framework*. Journal of Environmental Psychology, **15**, 169–182, 1995.

Leighton, T. G., and Walton, A. J. (1987). *An experimental study of the sound emitted from gas bubbles in a liquid*. European Journal of Physics, 8(2), 1987.

Leighton, T. (1994). *The Acoustic Bubble*. Academic Press, London.

Lercher, P., and Schulte-Fortkamp, B. (2003). *The relevance of soundscape research to the assessment of noise annoyance at the community level*. Proceeding of ICBEN 2003, 225–231, July 2003, Rotterdam, The Netherlands.

Liu, J., Kang, J., Behm, H., and Luo, T. (2014). *Effects of landscape on soundscape perception: Soundwalks in city parks*. Landscape and Urban Planning, **123**, 30–40, 2014.

Lohrer, A. (2008). *Basic designing with water*. Birkhäuse GmbH, Basel, Switzerland.

Long, M. (2006). *Architectural Acoustics*. Elsevier Academic Press, London.

Mantiuk, R.K., Tomaszewska, A., and Mantiuk, R. (2012). *Comparison of four subjective methods for image quality assessment*. Wiley Online Library, 2478–2491.

Miedema, H.M. and Oudshoorn, C.G. (2001). *Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals*. Environmental Health Perspective, **109**, 409–416, 2001.

Miller, N. P. (2008). U*S National Parks and management of park soundscapes: A review*. Applied Acoustics, **69**, 77–92, 2008.

Minorikawa, G., Maruta, Y., and Nakaniwa, H. (2004). *Study on sound from stream of water passing through channel with step and its sound quality*. Proceeding of InterNoise 2004, 1-4, August 2004, Prague, Czech Republic.

Nasar, J., and Lin, Y.-H. (2003). *Evaluative responses to five kinds of water features*. Landscape Research, **28(4)**, 441–450, 2003.

Nilsson, M. E., Alvarsson, J., Rådsten-Ekman, M., and Bolin, K. (2010). *Auditory masking of wanted and unwanted sounds in a city park*. Noise Control Engineering Journal, **58(5)**, 524–531, 2010.

Osgood, C. E., (1952). *The nature and measurement of meaning*. Psychological Bulletin, **49(3)**, 197-237, 1952.

Payne, S.R. (2008). *Are perceived soundscapes within urban parks restorative?*. Proceeding of Acoustics 2008, 5521–5526, 29 June-4 July 2008, Paris, France.

Payne, S.R., (2013). *The production of a Perceived Restorativeness Soundscape Scale*. Applied Acoustics, **74**, 255–263, 2013.

Perkins, G. (1973). *The delight of a city: Water*. Concrete Quality, 99, 33,1973.

Perysinaki, A. M. (2010). *How do waterscape projects combine landscape design and natural processes to create dialogues that engage both culture and nature? The case of the Boston park system and the solar city*. World Wide Workshop for Young Environmental Scientists. Arcuile, France,2010.

Pheasant, R., Horoshenkov, K., Watts, G., and Barrett, B. (2008). *The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments tranquil spaces-quiet places?*. The Journal of the Acoustical Society of America, **123(3)**, 1446–1457, 2008.

Pijanowski, B., Farina, A., Gage, S., Dumyahn, S., and Krause, B. (2011). *What is soundscape ecology? An introduction and overview of an emerging new science*. Landscape Ecology, **26(9)**, 1213–1232, 2011.

Rabinowitz, P.M. (2000). *Noise-induced hearing loss*. American Academy of Family Physicians, **61**, 2759–2760, 2000.

Rådsten-Ekman, M., Axelsson, O., and Nilsson, M. E. (2013). *Effects of Sounds from Water on Perception of Acoustic Environments Dominated by Road-Traffic Noise*. Acta Acustica United with Acustica, **99(2)**, 218–225, 2013.

Raimbault, M., Lavandier, C., and Bérengier, M. (2003). *Ambient sound assessment of urban environments: field studies in two French cities*. Applied Acoustic, **64(12)**, 1241–1256, 2003.

Raimbault, M., and Dubois, D. (2005). *Urban soundscapes: Experiences and knowledge*. Cities, **22(5)**, 339–350, 2005.

Ren, X., and Kang, J. (2015). *Effects of the visual landscape factors of an ecological waterscape on acoustic comfort*. Applied Acoustics, **96**, 171–179, 2015.

Schafer, R. M. (1994). *The soundscape: our sonic environment and the tunning of the world.* Destiny Books, Vermont .

Schulte-Fortkamp, B., Jeon, J.Y., and Genuit, K. (2010). *Urban design with soundscape-Experiences of a Korean-German team*. Proceeding of ICA 2010, 20th International Conference on Acoustics. 1–6, Sydney, August 2010, Australia.

Smith, B.J., Peter, R.J., and Owen, S. (1997). *Acoustics and Noise control*, Prentice Hall, New Jersey.

Staal, M. A. (2004). *Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework*. NASA TM 2004, 212824, Ames Research Centre, Moffet Field, California.

Suter, A. (1991). *Noise and its effects*. Conference Consultant, Administrative Conference of the United States, Maryland, USA, 1991.

Suter, A.H., 1989. *The effects of noise on performance*. Conference Consultant, Administrative Conference of the United States , Maryland, USA, 1989.

UK Department of Transport. (1995). *Calculation of railways noise*, 1995. ISBN 011 5517545, The Department of Transport, London.

Ulrich, R.S. (1983). *Aesthetic and affective response to natural environment*. Human Behaviour and Environment: Advances in Theory and Research, **6**, 85-125, 1983.

Viollon, S., Lavandier, C., and Drake, C. (2002). *Influence of visual setting on sound ratings in an urban environment*. Applied Acoustics, **63(5)**, 493–511, 2002.

Watts, G. R., Pheasant, R. J., Horoshenkov, K. V., and Ragonesi, L. (2009). *Measurement and Subjective Assessment of Water Generated Sounds*. Acta Acustica United with Acustica, **95(6)**, 1032–1039, 2009.

WG2 European Commission (2002). *EU's FUTURE NOISE POLICY, WG2 – Dose/Effect-Position paper on dose response relationships between transportation noise and annoyance*. Luxembourg.

WHO/Europe (1999). *Guidelines for Community Noise*. World Health Organisation Office, Geneva, Switzerland.

WHO/Europe. (2012). *WHO Lares, Noie effects and morbidity*. World Health Organisation Office, Geneva, Switzerland.

Widmann, U., Lippold, R. and Fastl, H., (1998), *A computer program simulation post-masking for applications in sound analysis systems*. Proceedings of Noise-Con 1998, 451-456, Ypsilanti Michigan, USA, 1998.

Yang, W., and Kang, J. (2005a). *Acoustic comfort evaluation in urban open public spaces*. Applied Acoustics, **66(2)**, 211–229, 2005.

Yang, W., and Kang, J. (2005b). *Soundscape and Sound Preferences in Urban Squares: A Case Study in Sheffield*. Journal of Urban Design, **10(1)**, 61–80, 2005.

Yang, M., and Kang, J. (2013). *Psychoacoustical evaluation of natural and urban sounds in soundscapes*. The Journal of the Acoustical Society of America, **134(1)**, 840–851, 2013.

You, J., Lee, P. J., and Jeon, J. Y. (2010). *Evaluating water sounds to improve the soundscape of urban areas affected by traffic noise*. Noise Control Engineering Journal, **58(5)**, 477–483, 2010

Yu, L., and Kang, J. (2008). *Effects of social, demographical and behavioural factors on the sound level evaluation in urban open spaces*. The Journal of the Acoustical Society of America, 123(2), 772–83, 2008.

Yu, L., and Kang, J. (2010). *Factors influencing the sound preference in urban open spaces*. Applied Acoustics, **71(7)**, 622–633, 2010.

Zimmermann, A., Knocke, M., and Robinson, M. (2011). *Constructing landscape: materials, techniques, structural components*. Birkhäuser GmbH, Basel, Switzerland.

Appendix A: Audio-only Test

This Appendix illustrates the questionnaire used for the audio-only test.

Name		**Surname**	
Gender	Male ☐	Female ☐	
Age (years)			
Nationality			

Confirm you have no hearing difficulties (e.g. Tinnitus) by ticking this box ☐

PRACTICE TEST		
Test number	**Sound 1 preferred**	**Sound 2 preferred**
PRACTICE 1	☐	☐
PRACTICE 2	☐	☐
PRACTICE 3	☐	☐
PRACTICE 4	☐	☐
PRACTICE 5	☐	☐

LISTENING TESTS – Part 1: Sound preference		
Test number	**Sound 1 preferred**	**Sound 2 preferred**
TEST 1	☐	☐
TEST 2	☐	☐
TEST 3	☐	☐
TEST 4	☐	☐
TEST 5	☐	☐
TEST 6	☐	☐
TEST 7	☐	☐
TEST 8	☐	☐
TEST 9	☐	☐
TEST 10	☐	☐
TEST 11	☐	☐
TEST 12	☐	☐
TEST 13	☐	☐
TEST 14	☐	☐
TEST 15	☐	☐
TEST 16	☐	☐
TEST 17	☐	☐
TEST 18	☐	☐
TEST 19	☐	☐
TEST 20	☐	☐

TEST 21		
TEST 22		
TEST 23		
TEST 24		
TEST 25		
TEST 26		
TEST 27		
TEST 28		
TEST 29		
TEST 30		
Test number	**Sound 1 preferred**	**Sound 2 preferred**
TEST 31		
TEST 32		
TEST 33		
TEST 34		
TEST 35		
TEST 36		
TEST 37		
TEST 38		
TEST 39		
TEST 40		
TEST 41		
TEST 42		
TEST 43		
TEST 44		
TEST 45		
TEST 46		
TEST 47		
TEST 48		
TEST 49		
TEST 50		
TEST 51		
TEST 52		
TEST 53		
TEST 54		
TEST 55		

If you have any comment about the sounds you heard in the tests, or any other comment, please write them in this box (optional).

Appendix B: Visual-only Test

This Appendix illustrates the questionnaire used for the visual-only test.

Name .... **Surname** ....

PRACTICE TEST		
Test number	**Image 1 preferred**	**Image 2 preferred**
PRACTICE 1	☐	☐
PRACTICE 2	☐	☐

VISUAL TESTS		
Test number	**Image 1 preferred**	**Image 2 preferred**
TEST 1	☐	☐
TEST 2	☐	☐
TEST 3	☐	☐
TEST 4	☐	☐
TEST 5	☐	☐
TEST 6	☐	☐
TEST 7	☐	☐
TEST 8	☐	☐
TEST 9	☐	☐
TEST 10	☐	☐
TEST 11	☐	☐
TEST 12	☐	☐
TEST 13	☐	☐
TEST 14	☐	☐
TEST 15	☐	☐
TEST 16	☐	☐
TEST 17	☐	☐
TEST 18	☐	☐
TEST 19	☐	☐
TEST 20	☐	☐
TEST 21	☐	☐
TEST 22	☐	☐
TEST 23	☐	☐
TEST 24	☐	☐
TEST 25	☐	☐
TEST 26	☐	☐
TEST 27	☐	☐
TEST 28	☐	☐
TEST 29	☐	☐
TEST 30	☐	☐

Test number	Image 1 preferred	Image 2 preferred
TEST 31	☐	☐
TEST 32	☐	☐
TEST 33	☐	☐
TEST 34	☐	☐
TEST 35	☐	☐
TEST 36	☐	☐
TEST 37	☐	☐
TEST 38	☐	☐
TEST 39	☐	☐
TEST 40	☐	☐
TEST 41	☐	☐
TEST 42	☐	☐
TEST 43	☐	☐
TEST 44	☐	☐
TEST 45	☐	☐

If you have any comment about the images you saw in the tests, or any other comment, please write them in this box (optional).

Appendix C: Audio-visual Test

This Appendix illustrates the questionnaire used for the audio-visual test.

Name .... **Surname** ....

PRACTICE TEST		
Test number	**Feature 1 preferred**	**Feature 2 preferred**
PRACTICE 1	☐	☐
PRACTICE 2	☐	☐

TESTS		
Test number	**Feature 1 preferred**	**Feature 2 preferred**
TEST 1	☐	☐
TEST 2	☐	☐
TEST 3	☐	☐
TEST 4	☐	☐
TEST 5	☐	☐
TEST 6	☐	☐
TEST 7	☐	☐
TEST 8	☐	☐
TEST 9	☐	☐
TEST 10	☐	☐
TEST 11	☐	☐
TEST 12	☐	☐
TEST 13	☐	☐
TEST 14	☐	☐
TEST 15	☐	☐
TEST 16	☐	☐
TEST 17	☐	☐
TEST 18	☐	☐
TEST 19	☐	☐
TEST 20	☐	☐
TEST 21	☐	☐
TEST 22	☐	☐
TEST 23	☐	☐
TEST 24	☐	☐
TEST 25	☐	☐
TEST 26	☐	☐
TEST 27	☐	☐
TEST 28	☐	☐
TEST 29	☐	☐
TEST 30	☐	☐

Test number	Feature 1 preferred	Feature 2 preferred
TEST 31	☐	☐
TEST 32	☐	☐
TEST 33	☐	☐
TEST 34	☐	☐
TEST 35	☐	☐
TEST 36	☐	☐
TEST 37	☐	☐
TEST 38	☐	☐
TEST 39	☐	☐
TEST 40	☐	☐
TEST 41	☐	☐
TEST 42	☐	☐
TEST 43	☐	☐
TEST 44	☐	☐
TEST 45	☐	☐

If you have any comment about the features you heard and saw in the tests, or any other comment, please write them in this box (optional).

Appendix D: Semantic Differential Test, Categorisation and Evocation

This Appendix illustrates the questionnaires used for the semantic differential test, as well as the test for qualitative categorisation and evocation of water sounds.

LISTENING TEST – Part 1: Semantic differential test

- **How relaxing is this sound?**

Very relaxing	Relaxing	Neither relaxing nor stressful	Stressful	Very stressful
☐	☐	☐	☐	☐

- **How natural is this sound?**

Very natural	Natural	Neither natural nor artificial	Artificial	Very artificial
☐	☐	☐	☐	☐

- **How refreshing is this sound?**

Very refreshing	Refreshing	Neither refreshing nor weary	Weary	Very weary
☐	☐	☐	☐	☐

- **How unsteady is this sound?**

Very unsteady	Unsteady	Neither unsteady nor steady	Steady	Very steady
☐	☐	☐	☐	☐

- **How familiar is this sound?**

Very familiar	Familiar	Neither familiar nor unfamiliar	Unfamiliar	Very unfamiliar
☐	☐	☐	☐	☐

- **How enveloping (e.g. surrounding) is this sound?**

Very	Enveloping	Neither enveloping nor directional	Directional	Very directional
☐	☐	☐	☐	☐

- **How rough is this sound?**

Very rough	Rough	Neither rough nor smooth	Smooth	Very smooth
☐	☐	☐	☐	☐

- **How sharp is this sound?**

Very sharp	Sharp	Neither sharp nor flat	Flat	Very flat
☐	☐	☐	☐	☐

- **How fast is this sound?**

Very fast	Fast	Neither fast nor slow		Very
☐	☐	☐	☐	☐

LISTENING TEST – Part 2: Qualitative categorisation and evocation

- **Indicate which type of water feature this sound makes you think of.**

Waterfall	Fountain	Natural stream	None of them
☐	☐	☐	☐

- **If the sound evokes anything to you, please explain what it makes you think of.**

- **Does this sound make you think of a manmade water feature? (e.g. water falling into a drain/container or a tap)**

Yes	No
☐	☐

- **Does this sound make you think about rainfall?**

Yes	No
☐	☐

Appendix E: Visual Categorisation Test

This Appendix illustrates the questionnaire used for the online test in view of visual categorisation of water features tested.

VISUAL TEST

This visual test includes ten images of ten different water features and should take no more than 3 minutes to be completed. The aim of the test is to understand whether each water feature appears as natural, manmade or neither. Before answering this question for each water feature, please take a minute to familiarise yourself with the water features tested by looking at the ten images shown below. Once you have done this, you can press CONTINUE at the bottom of the page to start the test.

* Required

1. Gender *…………….

2. Age *……………

3. Nationality *…………………………………

Image 1

Image 2

Image 3

Image 4

Image 5

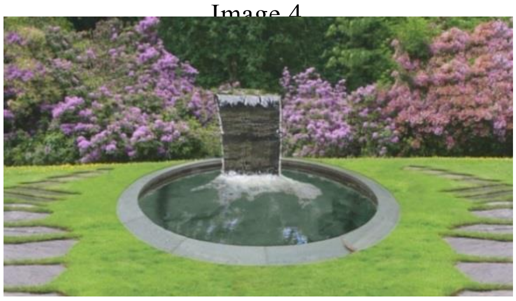


Image 6

Image 7

Image 8

Image 9

Image 10

Now focus your attention on the water features' displays and select your response for each of the ten images.

Image 1

Indicate which type of water feature image 1 makes you think of. * (*Mark only one box)*

Natural ☐ Manmade ☐ Neutral ☐

Image 2

Indicate which type of water feature image 2 makes you think of. * (*Mark only one box)*

Natural ☐ Manmade ☐ Neutral ☐

Image 3

Indicate which type of water feature image 3 makes you think of. * (*Mark only one box)*

Natural Manmade Neutral

Image 4

Indicate which type of water feature image 4 makes you think of. * (*Mark only one box)*

Natural Manmade Neutral

Image 5

Indicate which type of water feature image 5 makes you think of. * (*Mark only one box)*

Natural Manmade Neutral

Image 6

Indicate which type of water feature image 6 makes you think of. * (*Mark only one box)*

Natural	Manmade	Neutral
☐	☐	☐

Image 7

Indicate which type of water feature image 7 makes you think of. * (*Mark only one box)*

Natural	Manmade	Neutral
☐	☐	☐

Image 8

Indicate which type of water feature image 8 makes you think of. * (*Mark only one box)*

Natural	Manmade	Neutral
☐	☐	☐

Image 9

Indicate which type of water feature image 9 makes you think of. * (*Mark only one box)*

Natural	Manmade	Neutral
☐	☐	☐

Image 10

Indicate which type of water feature image 10 makes you think of. * (*Mark only one box)*

Natural	Manmade	Neutral
☐	☐	☐

Appendix F: Qualitative "Open-ended" Descriptions of Water Sounds

Results from the qualitative "open-ended" descriptions are given as those most commonly mentioned for each water feature tested.

NATURAL STREAM (ST) – Evocation results
Sounds from a small stream
Water flowing into a container
It is enjoyable like a bird song and reminds me the spring time.
Sound from a river in a raining day
Sounds from washing hands
Sounds from a small river
Sounds in a botanic garden
Walking under the rain (enjoy-fully!)
Water flowing into a pond

CASCADE (CA) – Evocation results
Sounds from a river during summer time
Very fast stream
Sounds from rainfall
Countryside in my city (Syria)
A neither fast nor slow river
Sounds from a river
Flowing water in a stream
Heavy rain on street
Good environment and fresh air quite enjoyable
Small rivers on concrete
Rainfall
Shallow stream
Stream in a forest

FOUNTAIN 37 UPWARD JETS (FTW) – Evocation results
It sounds like having a shower or a bath
Gully/drain
Flowing water into a cave
Water falling into a drain
Fountains sounds in Islamic old house
Waterfall plus rainfall
Heavy rainfall
Manmade feature
Rainfall into a pool
Mixed sounds
Water dripping from a drainpipe
River sound
Fountain in a shopping mall

SMALL HOLES WATERFALL (SHW)– Evocation results
Rainfall
Heavy rainfall in urban settings
Heavy rainfall
Sounds from a small waterfall
A stream over rocks and slight waterfall
Sounds in park
Rainfall on concrete
Small waterfall
Heavy rainfall in a forest

DOME FOUNTAIN (DF)– Evocation results
Water running down streets
Rainfall
Cold winter
Heavy rainfall+ speech
Sounds from a big river
Rainfall in city setting
Overflowing roof drains
Rainfall + annoying background noise
Sounds from rainfall into a drain

FOAM FOUNTAIN (FF)– Evocation results
Sounds from washing hands
Natural stream with someone moving in it
Small river in the mountain
Manmade movement of water
Tap water
Jumping water
Water in a tube
Washing dishes
Water pump
Water coming out hole
Natural waterfall

SAWTOOTH EDGE WATERFALL (SEW)– Evocation results
Tap water
Waterfall + fountain
Rainfall
Fast river
Fountain in a square
Rainfall + background noise
Small pool

LARGE JET (LJT)– Evocation results
Bath filling up
Filling up a bucket
Dripping water tap
Filling a glass of water
Tap water
Water flowing into a container
Annoying sound coming from the home's tank
Fountain
Rainfall from the roof of a small building
Natural cave
Natural stream + small waterfall
Heavy rainfall
A pipe overflowing

PLAIN EDGE WATERFALL (PEW)– Evocation results
TV-noise signal
Rainfall
A small waterfall
Sounds like heavy rainfall on a lake/river
No clear sound
Similar to a waterfall but it is windy
Water on concrete
Very cold weather

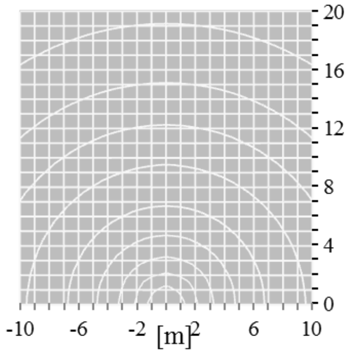
NARROW JET (NJT)– Evocation results
Water bath
Fountain jets over stones
Water flowing in a pond
Artificial water sounds
Water in a tube
Fishing
Flowing water into a drain
Rain in the hole of the street
Water Tap
Water growing from a pipe and falling to the ground

Appendix G: Sound Maps for Water Features used over RTN level of 40 dBA

Results of Sound maps for water features used over RTN level of 40 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

SHW



‘Optimum zone’ extends 25 to 33 m from

Figure G1

DF

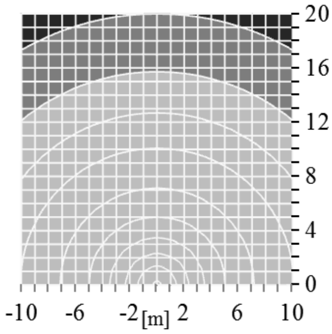


Figure G2

FF

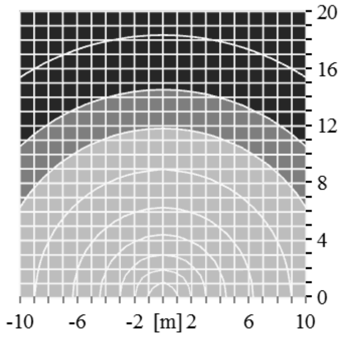
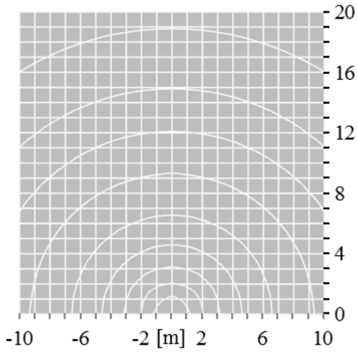


Figure G3

SEW



‘Optimum zone’ extends 32 to 43 m from

Figure G4

LJT

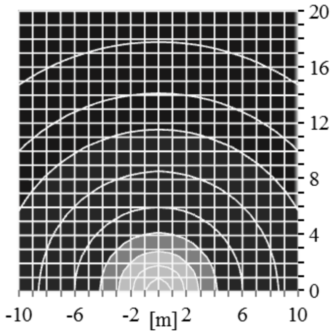
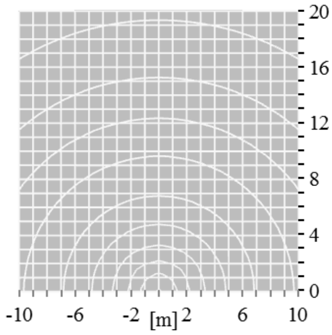


Figure G5

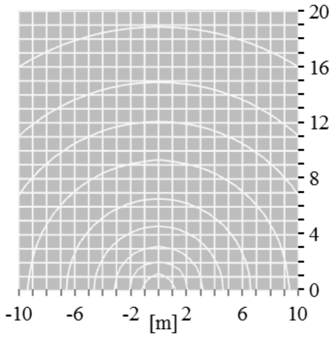
PEW



‘Optimum zone’ extends 33 to 44 m

Figure G6

NJT



‘Optimum zone’ extends 32 to 43 m from

Figure G7

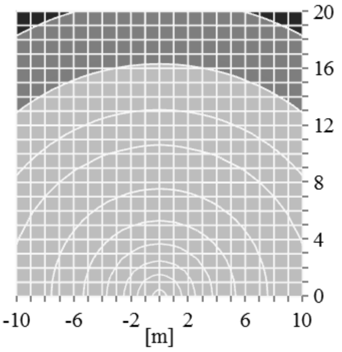
*Spreading sound: white line corresponds to 3 dBA change in level

Appendix H: Sound Maps for Water Features used over RTN level of 45 dBA

Results of Sound maps for water features used over RTN level of 45 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

SHW



'Optimum zone' extends up to 21 m

Figure H1

DF

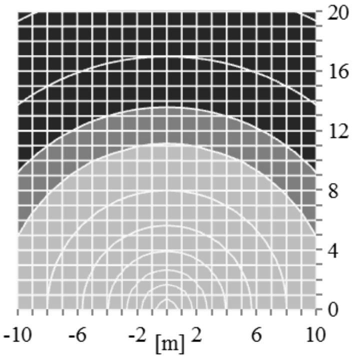


Figure H2

FF

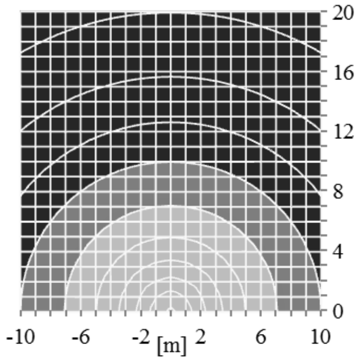


Figure H3

SEW

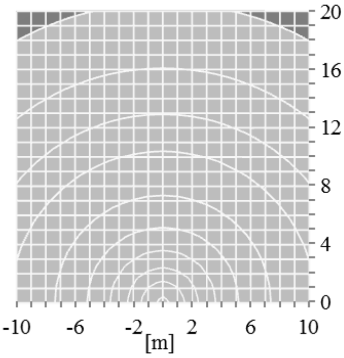
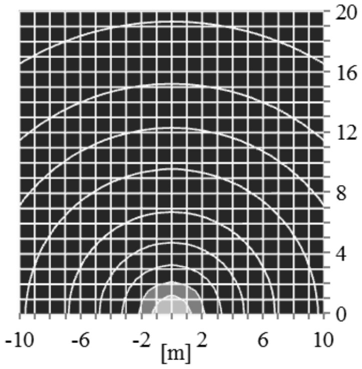


Figure H4

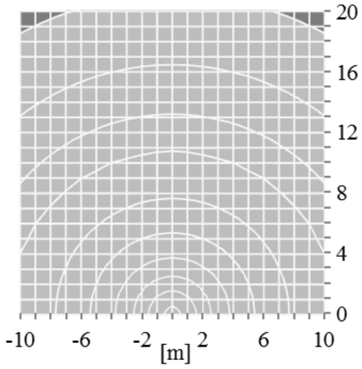
LJT



'Optimum zone' extends 20 to 27 m

Figure H5

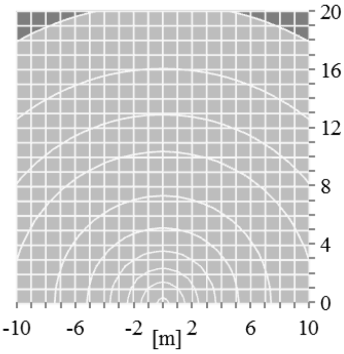
PEW



'Optimum zone' extends 21 to 28 m

Figure H6

NJT



'Optimum zone' extends 20 to 27 m

Figure H7

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix I: Sound Maps for Water Features used over RTN level of 50 dBA

Results of Sound maps for water features used over RTN level of 50 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant	Optimum zone	Water sound

SHW

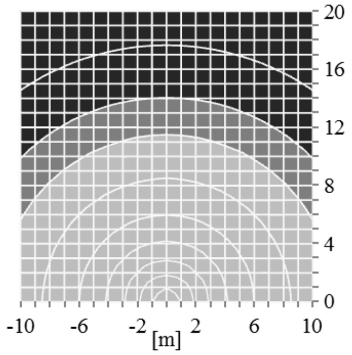


Figure I1

DF

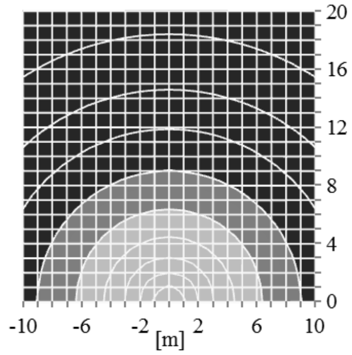


Figure I2

FF

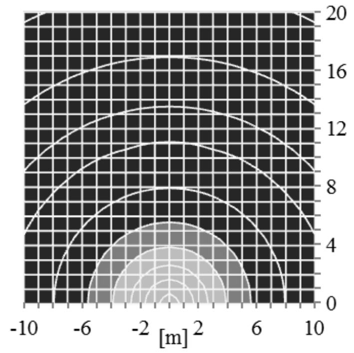


Figure I3

SEW

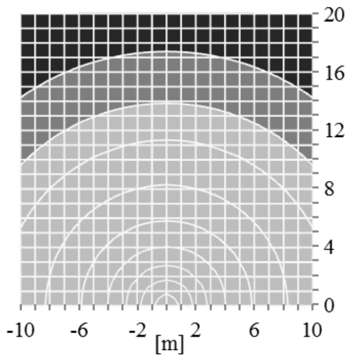


Figure I4

LJT

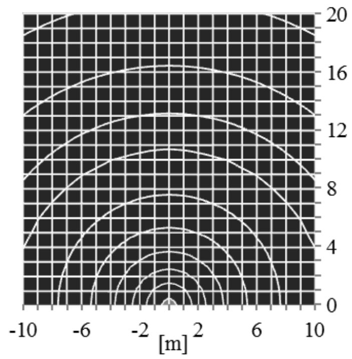


Figure I5

PEW

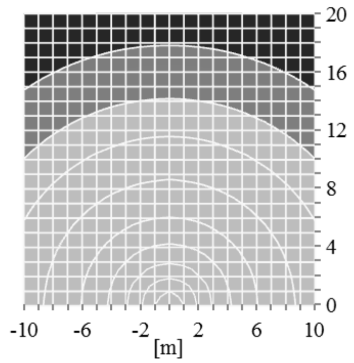


Figure I6

NJT

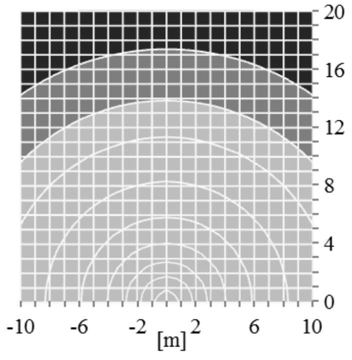


Figure I7

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix J: Sound Maps for Water Features used over RTN level of 55 dBA

Results of Sound maps for water features used over RTN level of 55 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant Optimum zone Water sound

ST

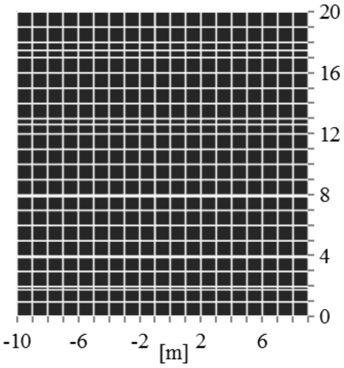


Figure J1

DF

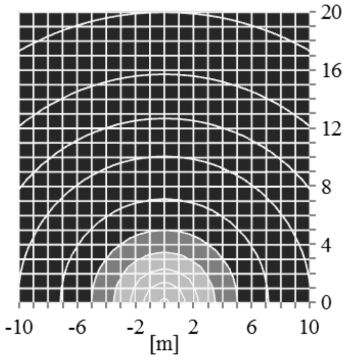


Figure J2

FF

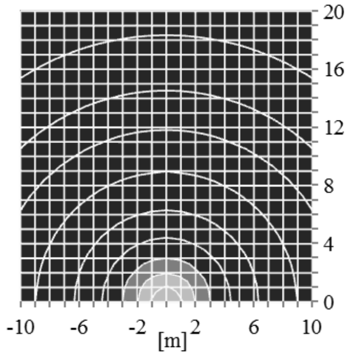


Figure J3

SEW

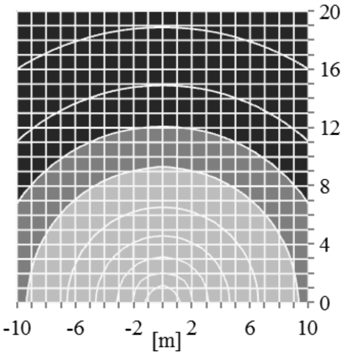


Figure J4

LJT

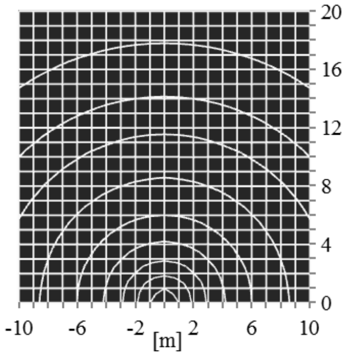


Figure J5

PEW

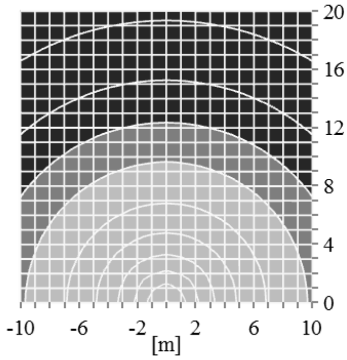


Figure J6

NJT

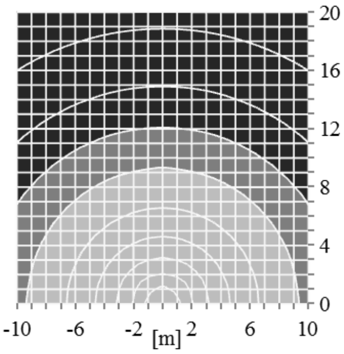


Figure J7

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix K: Sound Maps for Water Features used over RTN level of 60 dBA

Results of Sound maps for water features used over RTN level of 60 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

ST

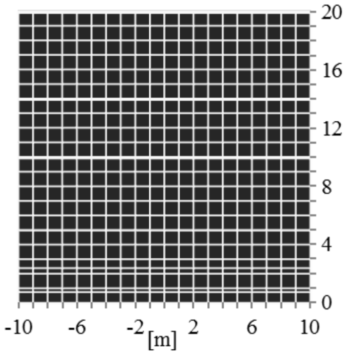


Figure K1

DF

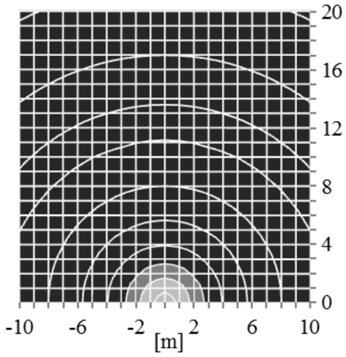


Figure K2

FF

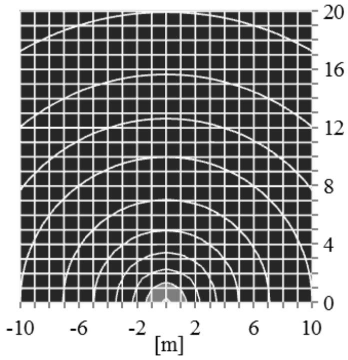


Figure K3

SEW

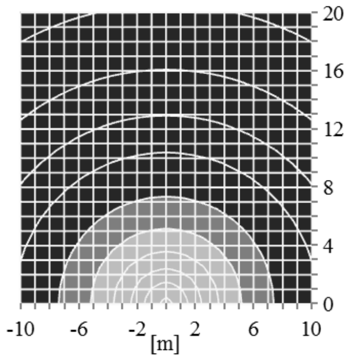


Figure K4

LJT

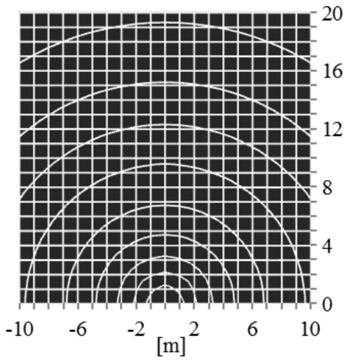


Figure K5

PEW

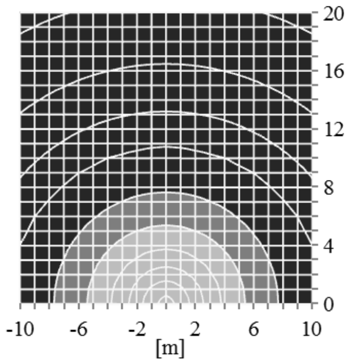


Figure K6

NJT

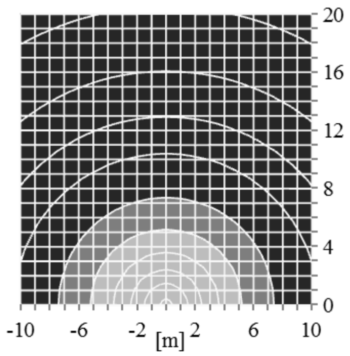


Figure K7

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix L: Sound Maps for Water Features used over RTN level of 65 dBA

Results of Sound maps for water features used over RTN level of 65 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

ST

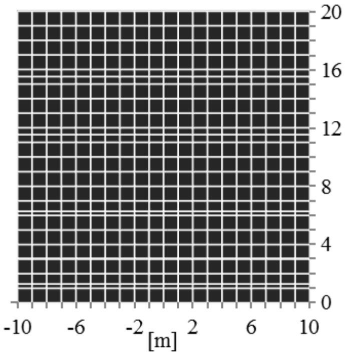


Figure L1

CA

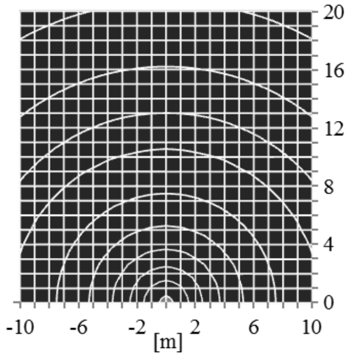


Figure L2

DF

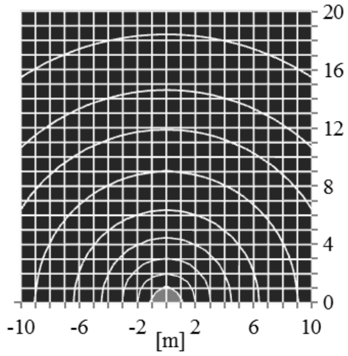


Figure L3

FF

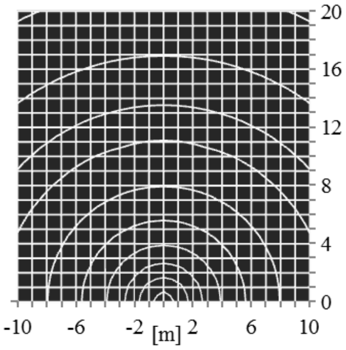


Figure L4

SEW

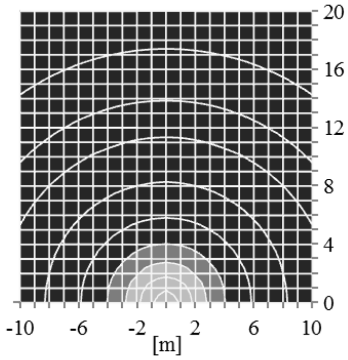


Figure L5

LJT

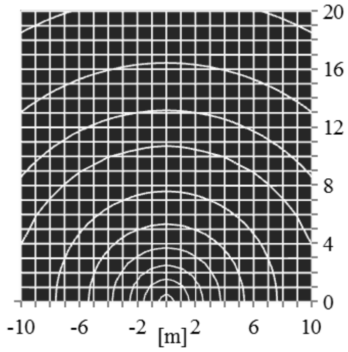


Figure L6

NJT

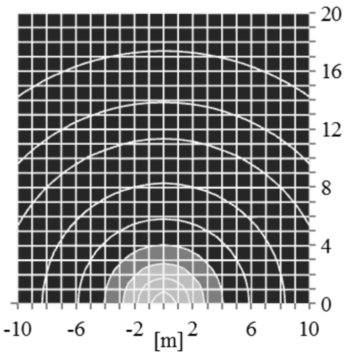


Figure L7

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix M: Sound Maps for Water Features used over RTN level of 70 dBA

Results of Sound maps for water features used over RTN level of 65 dBA are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

ST

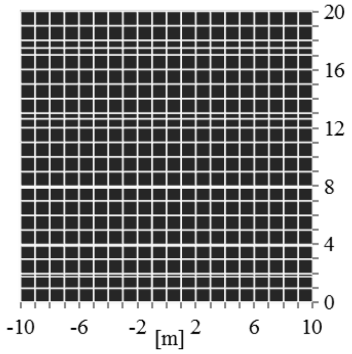


Figure M1

CA

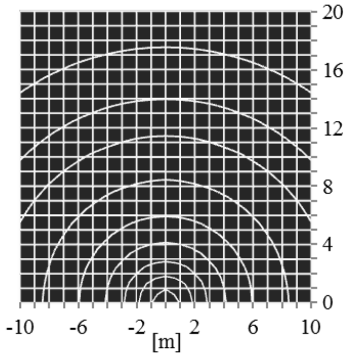


Figure M2

FTW

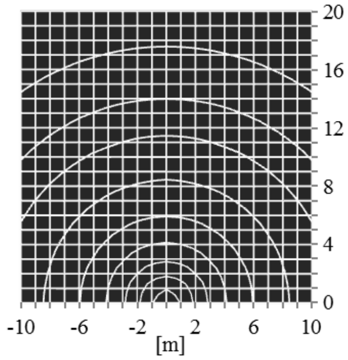


Figure M3

DF

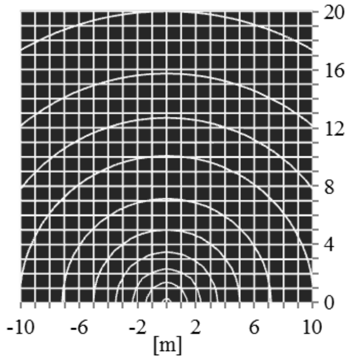


Figure M4

FF

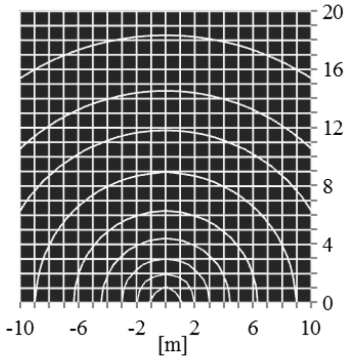


Figure M5

SEW

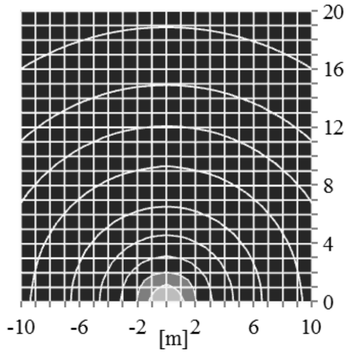


Figure M6

LJT

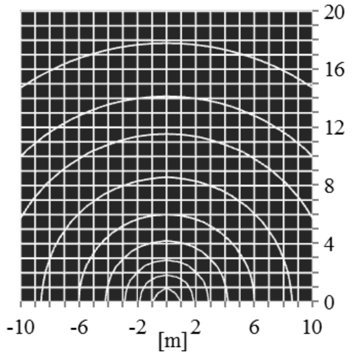


Figure M7

NJT

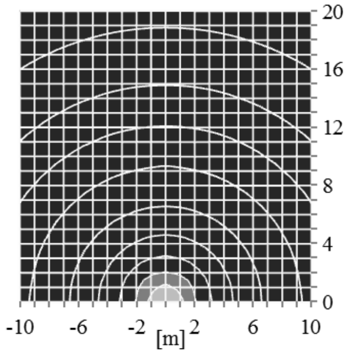


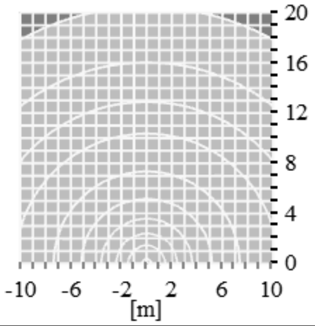
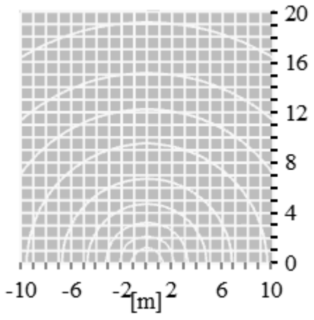
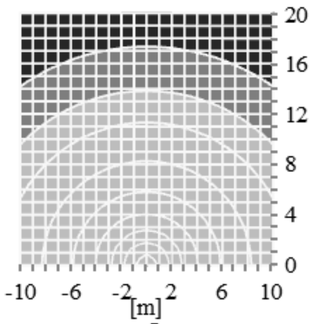
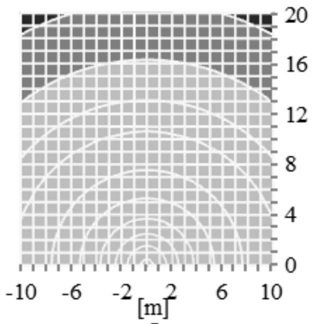
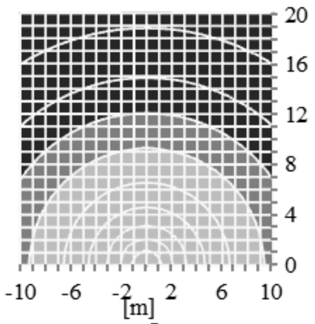
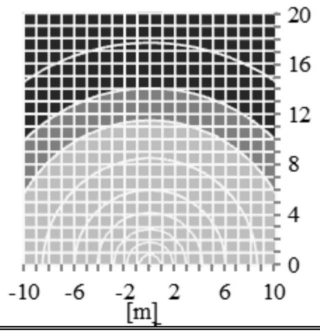
Figure M8

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix N: Sound Maps for Water Features with Different Flow Rates and RTN Levels

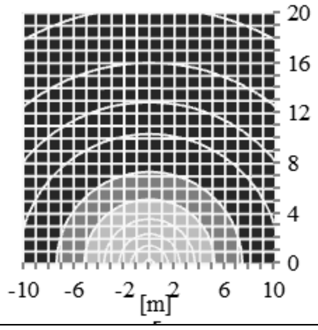
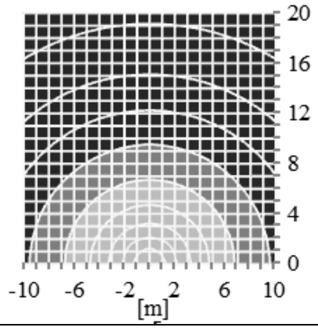
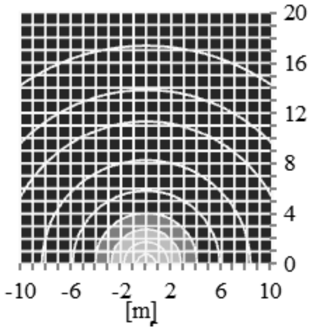
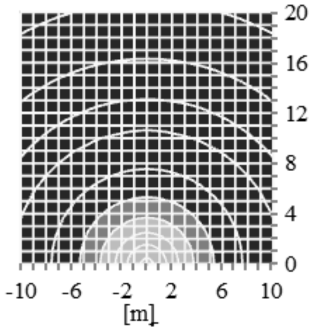
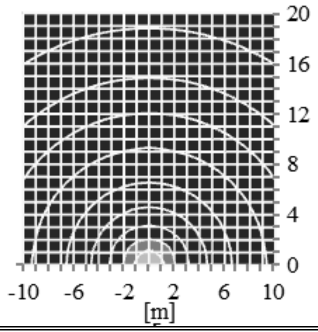
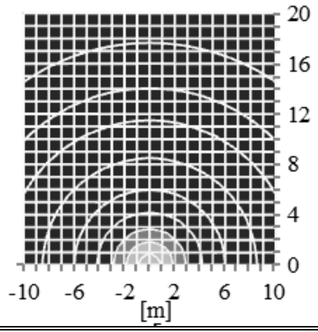
Results of sound maps for water features (SHW, CA and FTW with different flow rates and RTN levels are given in this appendix (refer to Figure 7.2 for calculation grid and location of sound sources).

■ RTN dominant ■ Optimum zone ■ Water sound

Small holes waterfall (SHW)		
	15 l/min	30 l/ min
RTN 40 dBA		
RTN 45 dBA		
RTN 50 dBA		

*Spreading sound: white line corresponds to 3 dBA change in level

Figure N1

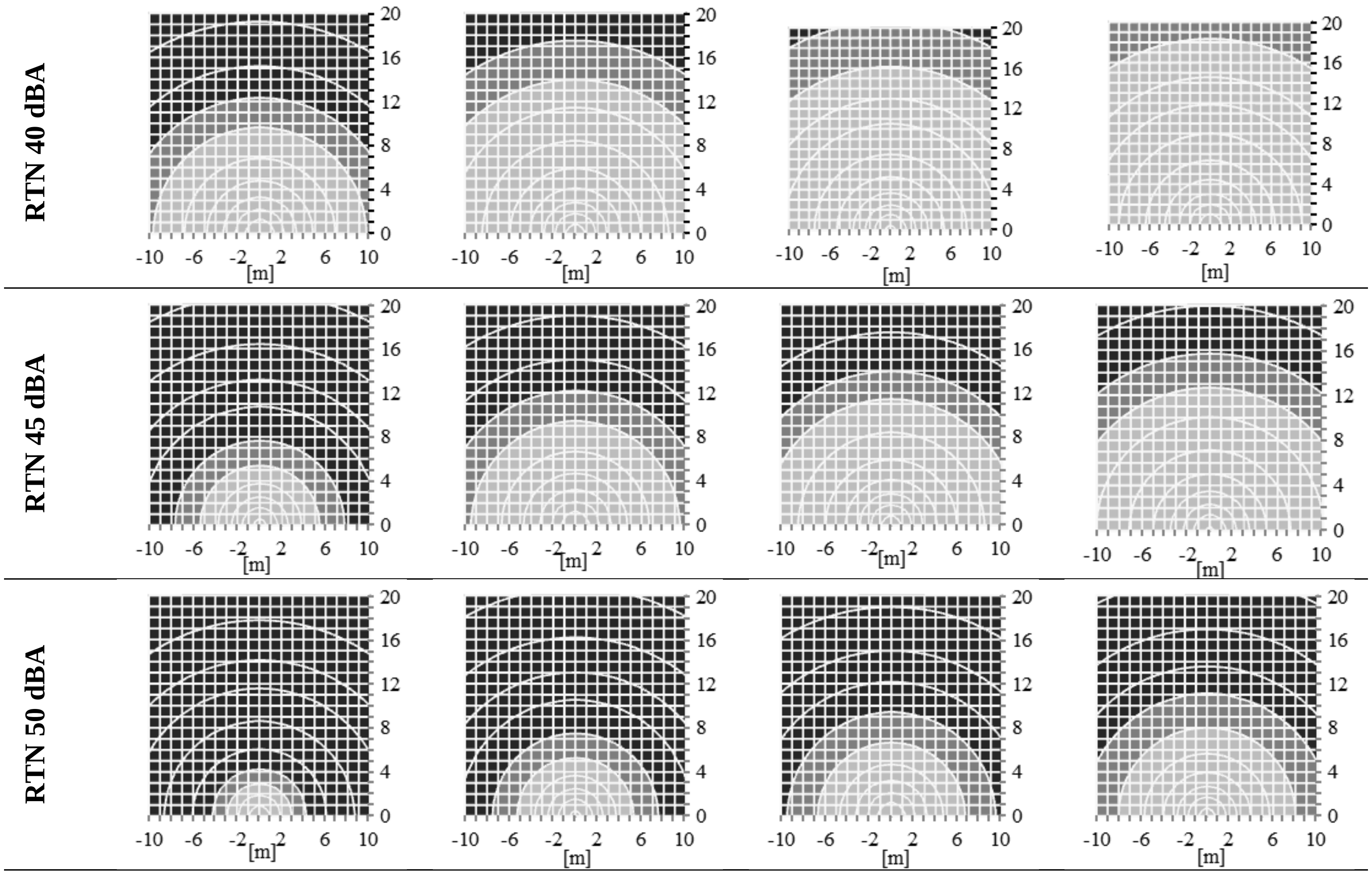
Small holes waterfall (SHW)		
	15 l/min	30 l/ min
RTN 55 dBA		
RTN 60 dBA		
RTN 65 dBA		

*Spreading sound: white line corresponds to 3 dBA change in level

Figure N2

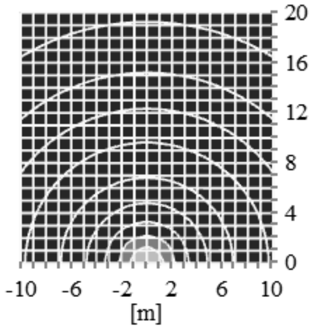
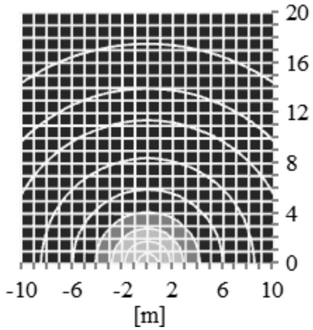
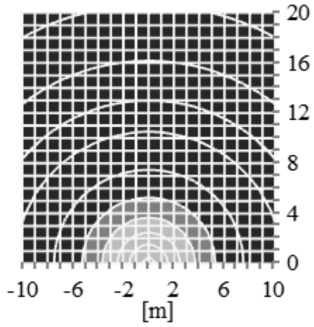
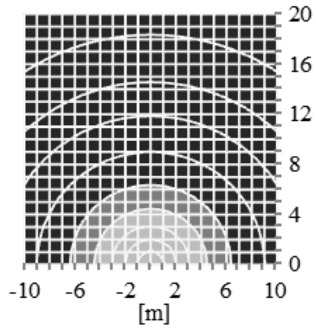
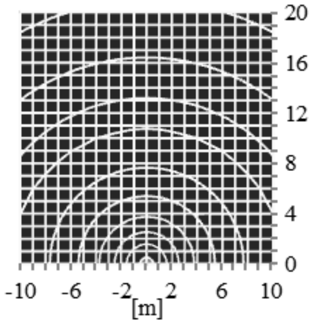
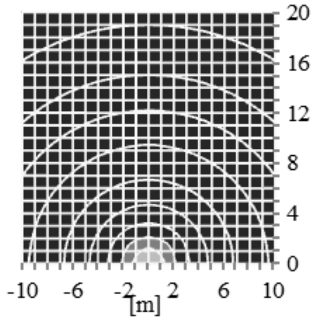
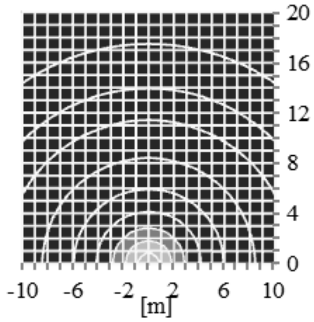
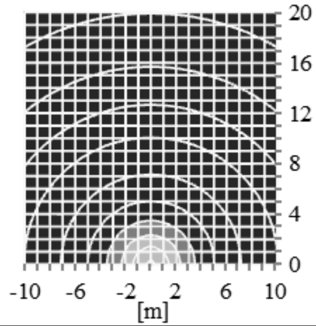
Cascade with four steps (CA)

5 l/min	15 l/ min	30 l/min	60 l/min



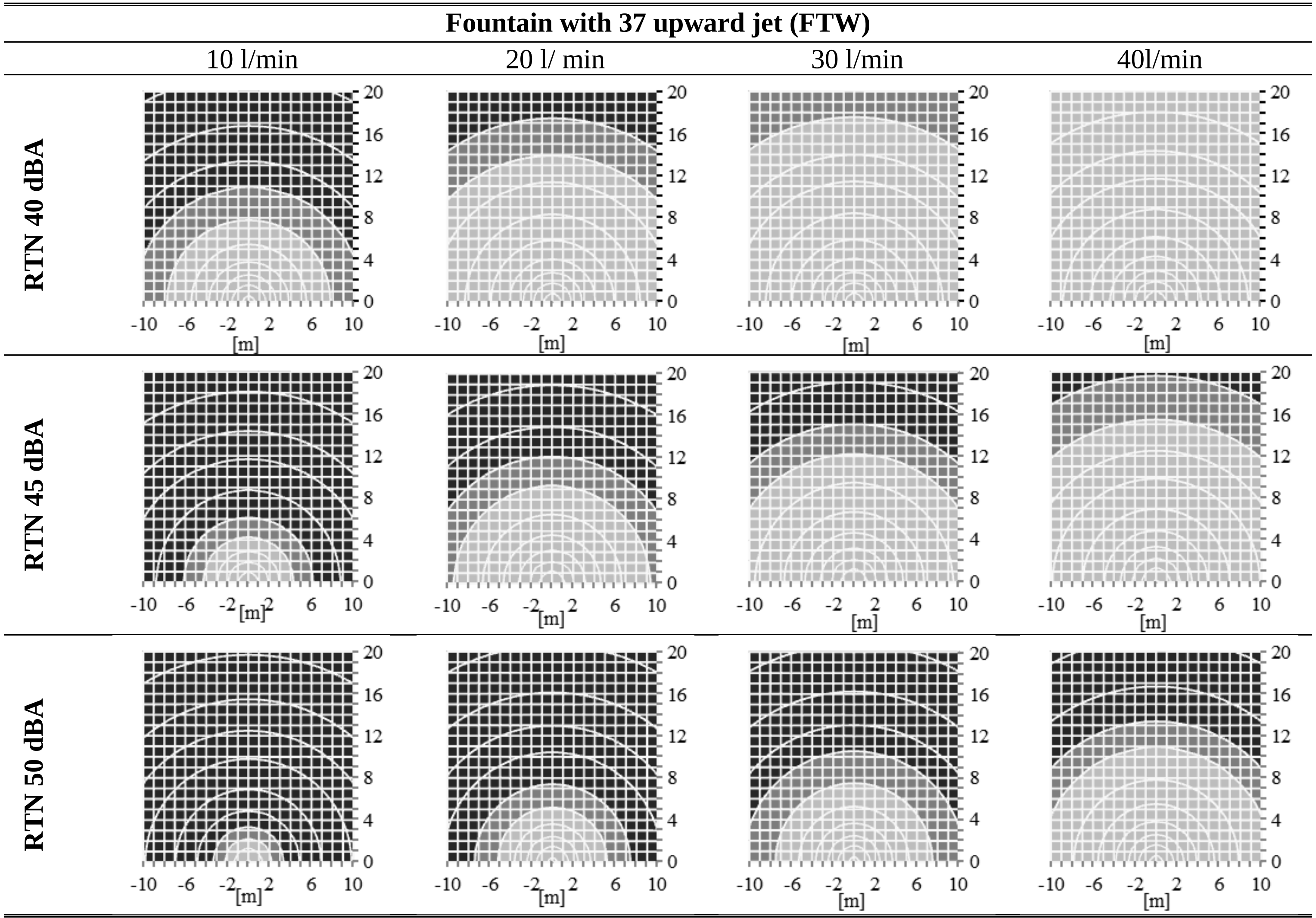
*Spreading sound: white line corresponds to 3 dBA change in level

Figure N3

Cascade with four steps (CA)				
	5 l/min	15 l/ min	30 l/min	60 l/min
RTN 55 dBA				
RTN 60 dBA				

*Spreading sound: white line corresponds to 3 dBA change in level

Figure N4

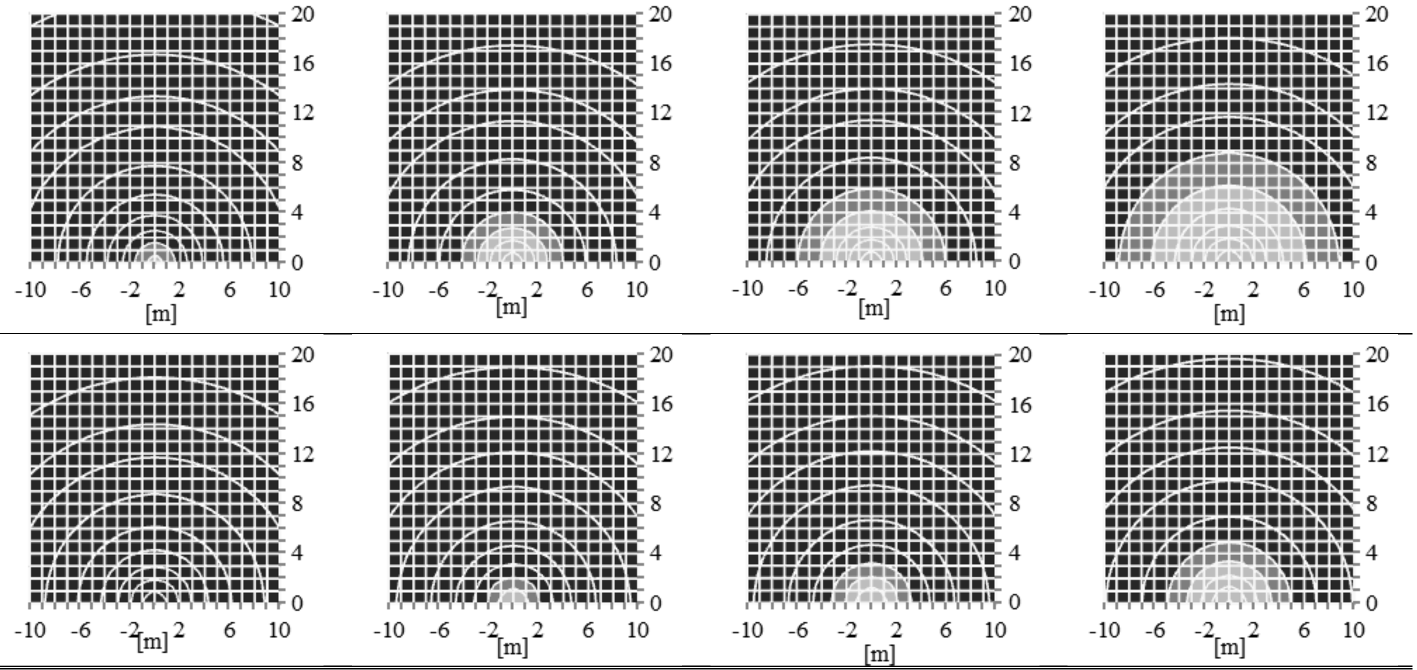


*Spreading sound: white line corresponds to 3 dBA change in level

Figure N5

Fountain with 37 upward jet (FTW)

	10 l/min	20 l/ min	30 l/min	40l/min
RTN 55 dBA				
RTN 60 dBA				



*Spreading sound: white line corresponds to 3 dBA change in level

Figure N6

Appendix O: Sound Maps for Multiple PEW used over RTN levels of 65 dBA

Results of sound maps are given in this appendix for multiple plain edge waterfalls (PEW) when they were used over RTN levels of 65 dBA at different positions in the grid of study (a-f) (refer to Figure 7.15 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

Plain edge waterfall (PEW)

(a)

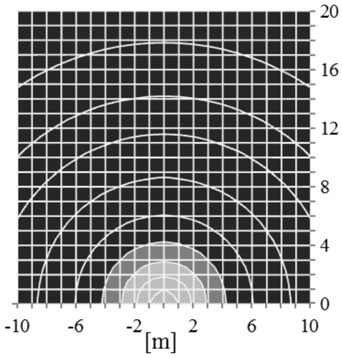


Figure O1

(b)

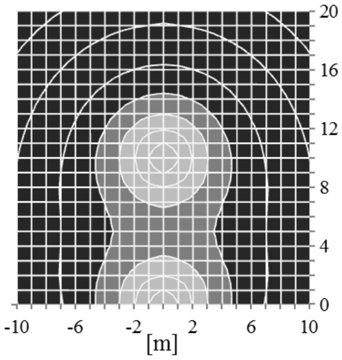


Figure O2

(c)

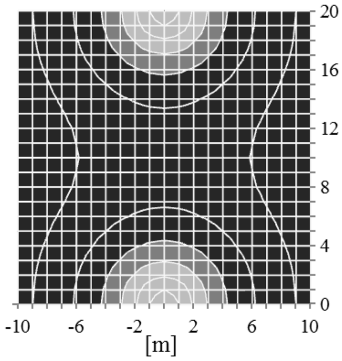


Figure O3

(d)

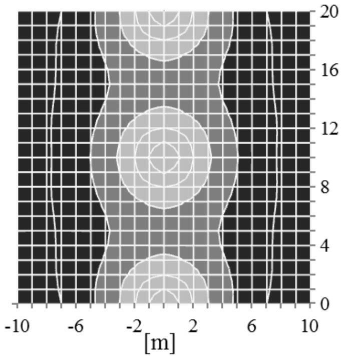


Figure O4

(e)

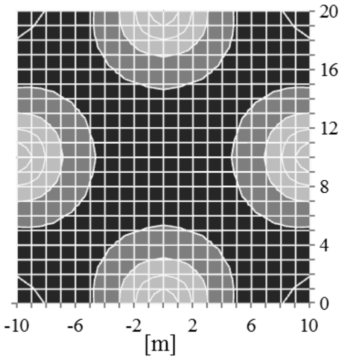


Figure O5

(f)

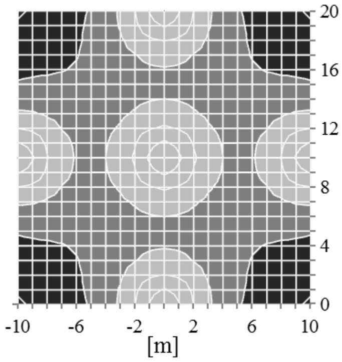


Figure O6

*Spreading sound: white line corresponds to 3 dBA change in level

Appendix P: Sound Maps for Multiple PEW used over RTN levels of 70 dBA

Results of sound maps are given in this appendix for multiple plain edge waterfalls (PEW) when they were used over RTN levels of 65 dBA at different positions in the grid of study (a-f) (refer to Figure 7.15 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound

Plain edge waterfall (PEW)

(a)

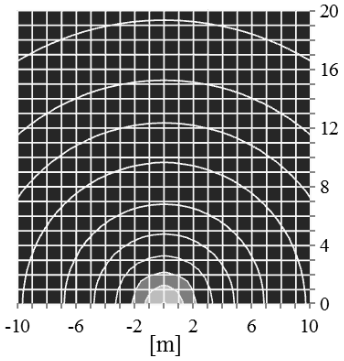


Figure P1

(b)

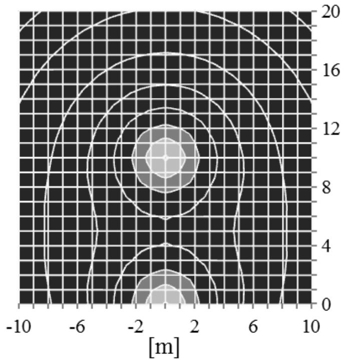


Figure P2

(c)

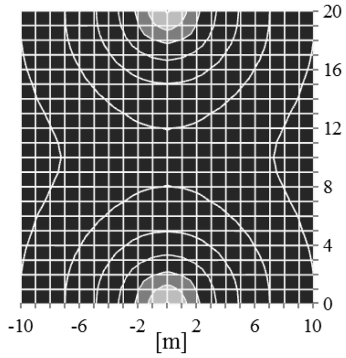


Figure P3

(d)

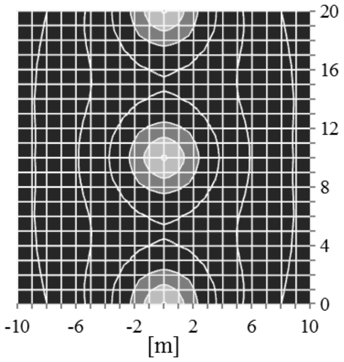


Figure P4

(e)

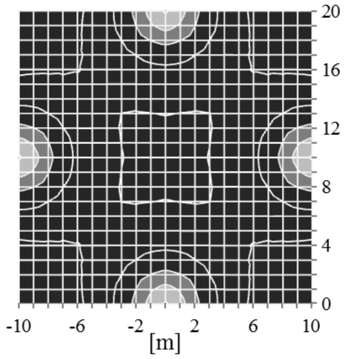


Figure P5

(f)

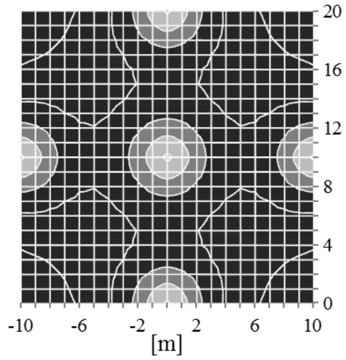


Figure P6

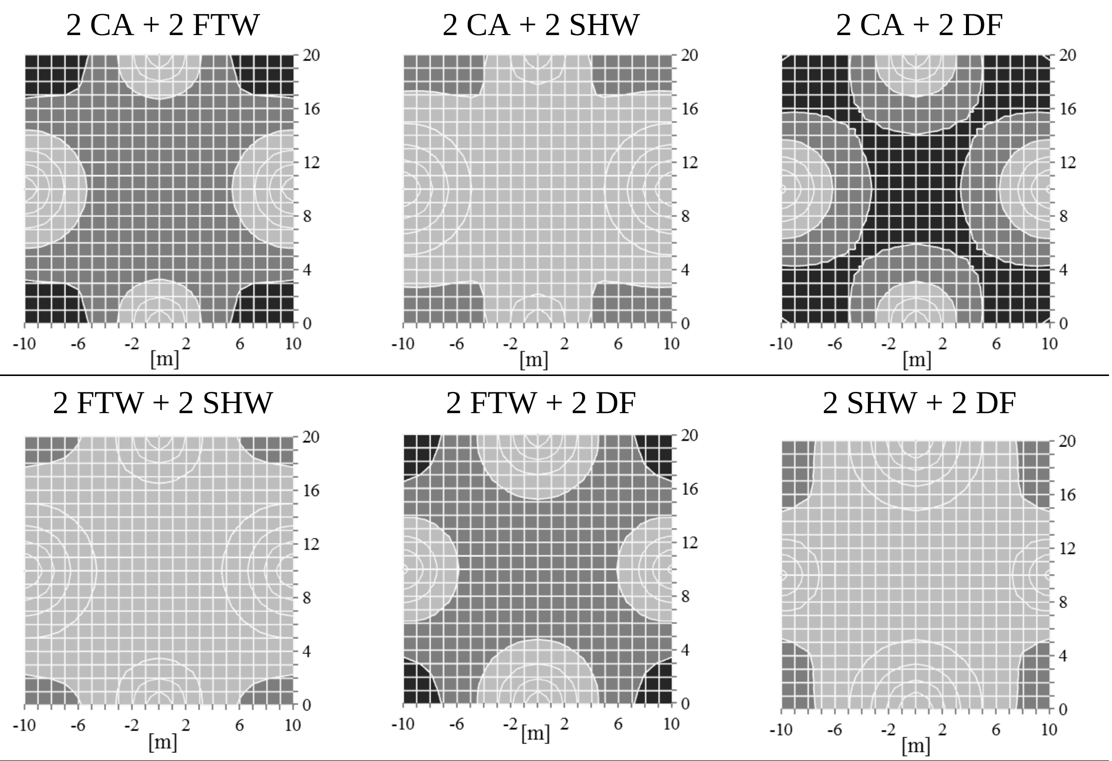
*Spreading sound: white line corresponds to 3 dBA change in level

Appendix Q: Sound maps for combinations of different water features used over RTN levels of 55 dBA

Results of sound maps are given in this appendix for multiple water features (CA, FTW and SHW) when they were used over RTN levels of 55 dBA over a 20 m × 20 m grid (refer to Figure 7.18 for calculation grid and location of sound sources).

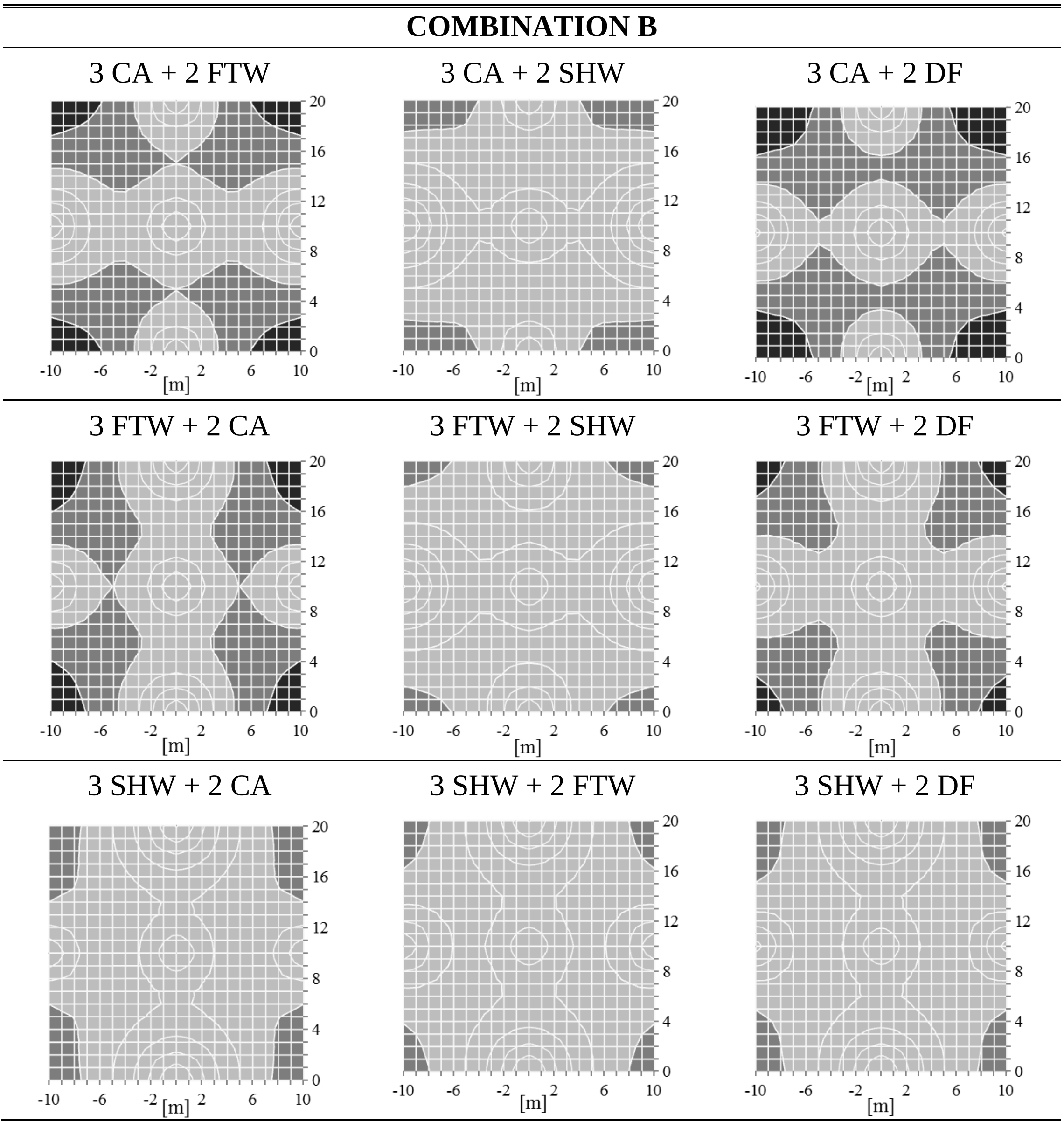
RTN dominant   Optimum zone   Water sound

COMBINATION A



*Spreading sound: white line corresponds to 3 dBA change in level

Figure Q1



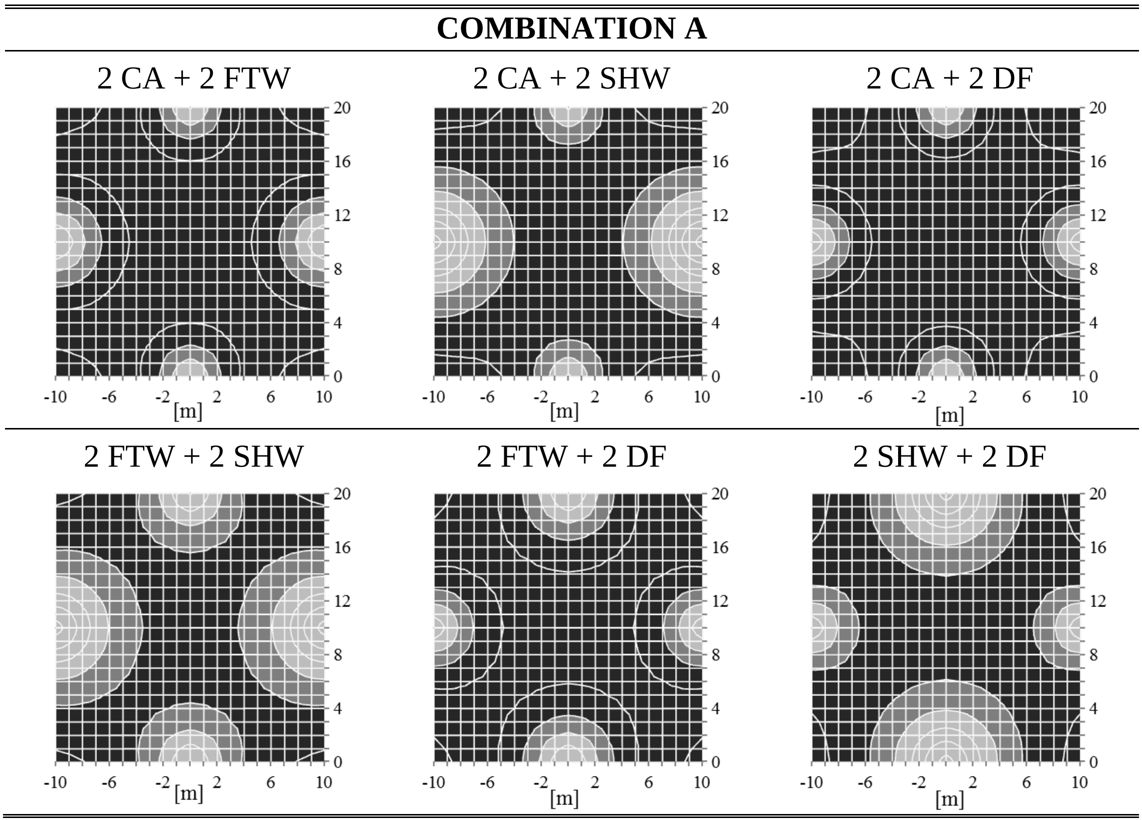
*Spreading sound: white line corresponds to 3 dBA change in level

Figure Q2

Appendix R: Sound maps for combinations of different water features used over RTN levels of 60 dBA

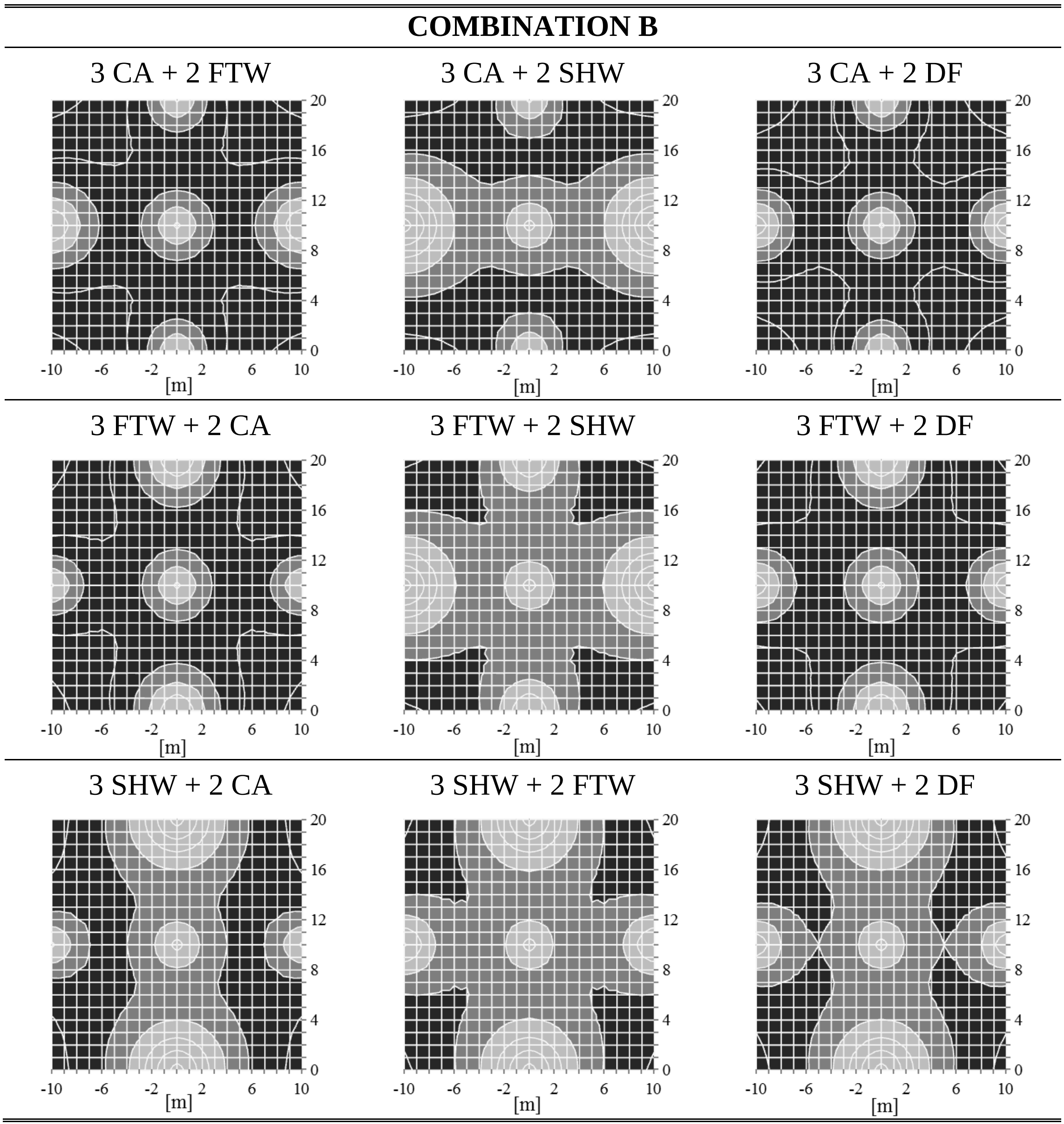
Results of sound maps are given in this appendix for multiple water features (CA, FTW and SHW) when they were used over RTN levels of 60 dBA over a 20 m × 20 m grid (refer to Figure 7.18 for calculation grid and location of sound sources).

RTN dominant   Optimum zone   Water sound



*Spreading sound: white line corresponds to 3 dBA change in level

Figure R1

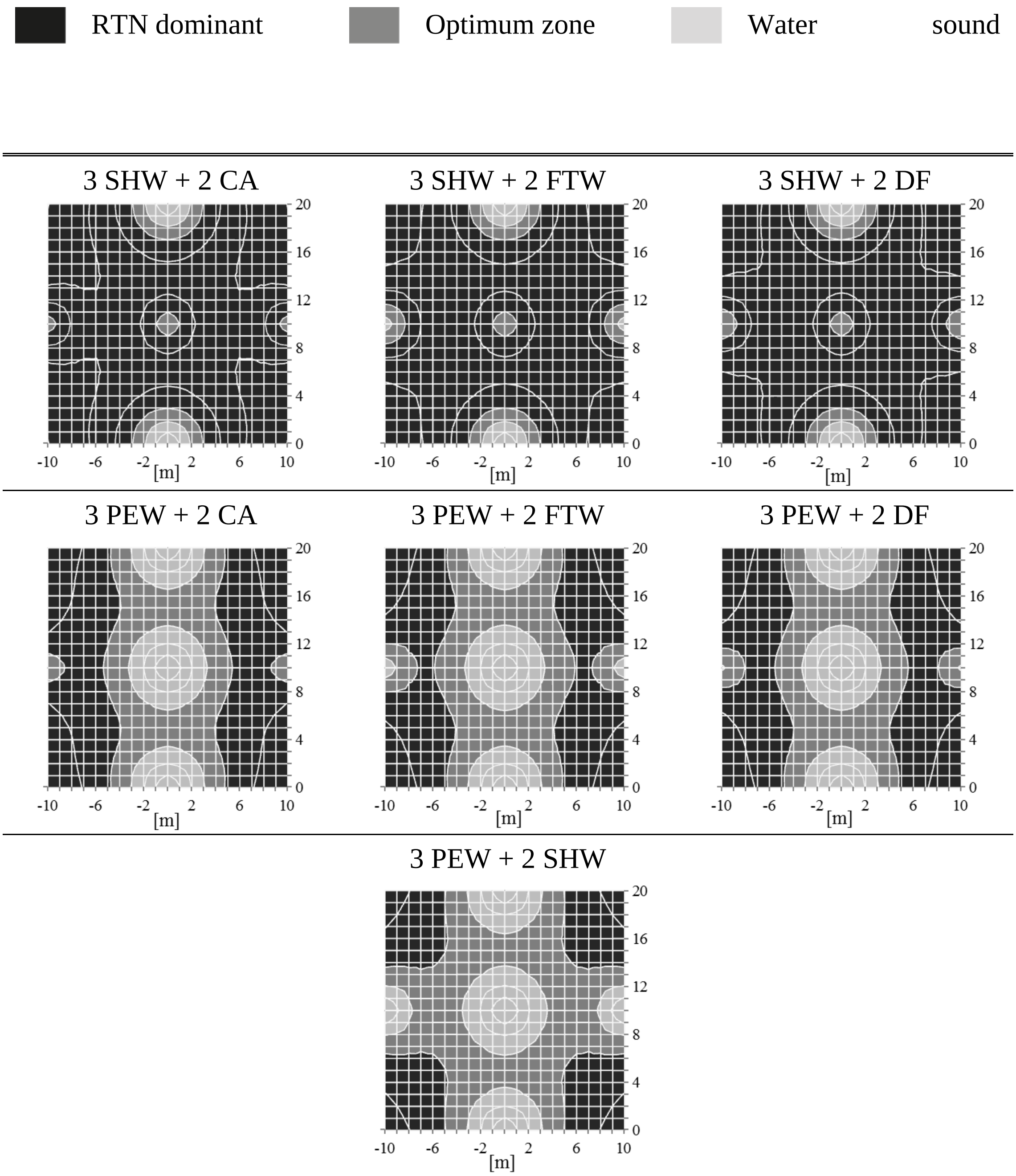


*Spreading sound: white line corresponds to 3 dBA change in level

Figure R2

Appendix S: Sound maps for combinations of different water features used over RTN levels of 65 dBA

Results of sound maps are given in this appendix for multiple water features (CA, FTW, SHW and PEW) when they were used over RTN levels of 65 dBA over a 20 m × 20 m grid (refer to Figure 7.18 for calculation grid and location of sound sources).



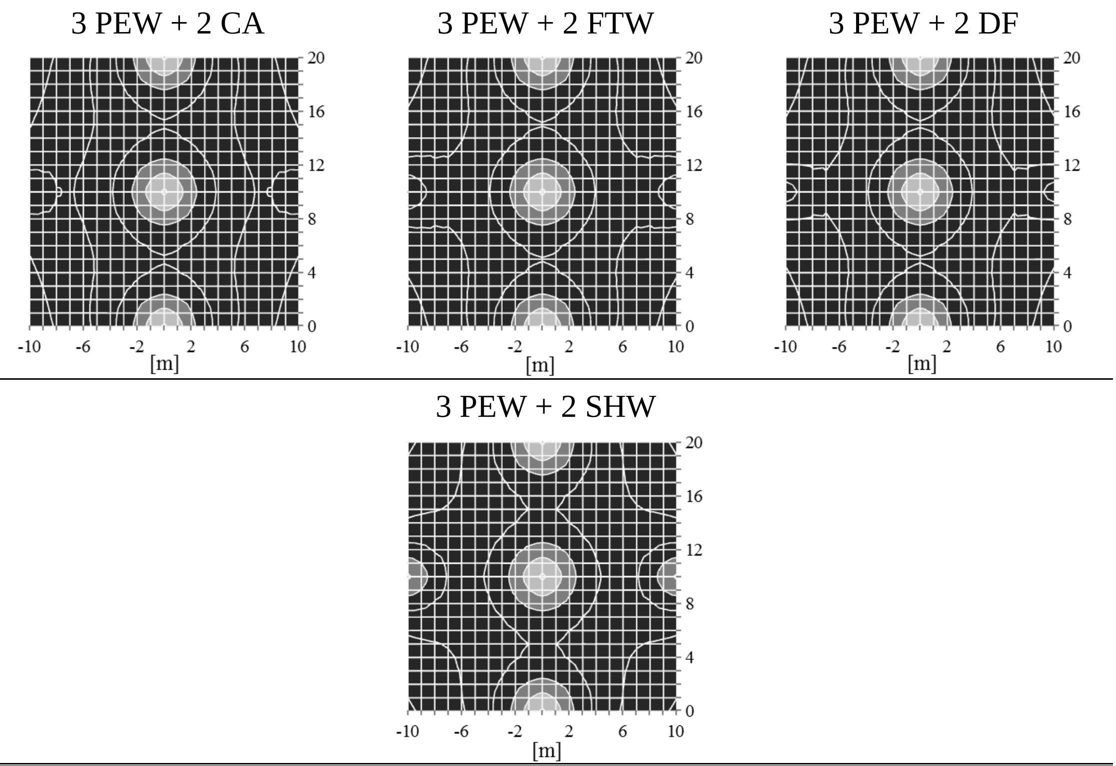
*Spreading sound: white line corresponds to 3 dBA change in level

Figure S1

Appendix T: Sound maps for combinations of different water features used over RTN levels of 70 dBA

Results of sound maps are given in this appendix for multiple water features (CA, FTW, SHW and PEW) when they were used over RTN levels of 70 dBA over a 20 m × 20 m grid. (refer to Figure 7.18 for calculation grid and location of sound sources).

RTN dominant | Optimum zone | Water sound



*Spreading sound: white line corresponds to 3 dBA change in level

Figure T1